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Monterey, California

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SCHEDULING THE RECRUITING AND MOS TRAINING OF ENLISTED MARINES

by

Darrin L. Whaley

September 2001

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Non-infantry enlisted Marines progress through Recruit Training, basic infantry training at Marine Combat Training (MCT), and Military Occupational Specialty (MOS) training before finally reporting to their first unit for duty. These Marines are the focus of this thesis. In fiscal year 1998, new recruits spent over 2,700 Marine-years wait time in an unproductive status while waiting on their next training schools to convene. Marine Corps manpower planners believe this level of wait time is unacceptable. This thesis develops two integer linear programs to plan recruiting and MOS school seat scheduling with the primary objective to minimize the time non-infantry enlisted Marines wait for MOS training. The first model, the Long-term Recruiting and MOS School Scheduler (LRAMS) plans both recruiting and MOS training to help MOS training schools' develop their training schedules two years prior to execution. The second model, the Short-term Adjusted Recruiting Model (STAR) is used after the MOS training school schedules are published to develop a coordinated recruiting schedule. Results indicate that wait time can be reduced significantly. For fiscal year 2001, LRAMS results provide a wait time of only 160 Marine-years.

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SCHEDULING THE RECRUITING AND MOS TRAINING OF ENLISTED MARINES

Darrin L. Whaley
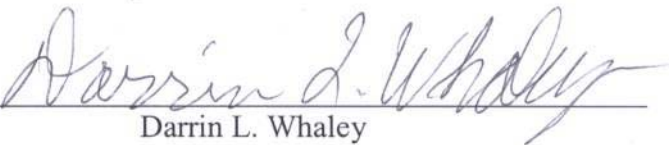Major, United States Marine Corps
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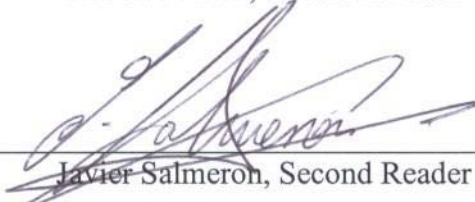## MASTER OF SCIENCE IN OPERATIONS RESEARCH

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ABSTRACT

Non-infantry enlisted Marines progress through Recruit Training, basic infantry training at Marine Combat Training (MCT), and Military Occupational Specialty (MOS) training before finally reporting to their first unit for duty. These Marines are the focus of this thesis. In fiscal year 1998, new recruits spent over 2,700 Marine-years (wait time) in an unproductive status while waiting on their next training schools to convene. Marine Corps manpower planners believe this level of wait time is unacceptable. This thesis develops two integer linear programs to plan recruiting and MOS school seat scheduling with the primary objective to minimize the time non-infantry enlisted Marines wait for MOS training. The first model, the Long-term Recruiting and MOS School Scheduler (LRAMS) plans both recruiting and MOS training to help MOS training schools' develop their training schedules two years prior to execution. The second model, the Short-term Adjusted Recruiting Model (STAR) is used after the MOS training school schedules are published to develop a coordinated recruiting schedule. Results indicate that wait time can be reduced significantly. For fiscal year 2001, LRAMS results provide a wait time of only 160 Marine-years.

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LIST OF ACRONYMS

GAMS   General Algebraic Modeling System

LRAMS   Long-term Recruiting and MOS School Scheduler

M&RA   Deputy Commandant of the Marine Corps for Manpower and Reserve Affairs

MCRC   Marine Corps Recruiting Command

MCT   Marine Combat Training

MOS   Military Occupational Specialty

STAR   Short-term Adjusted Recruiting Model

TBS   The Basic School

TECOM   Marine Corps Training and Education Command

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EXECUTIVE SUMMARY

Non-infantry enlisted Marines progress through Recruit Training, basic infantry training at Marine Combat Training (MCT), and Military Occupational Specialty (MOS) training before finally reporting to their original unit for duty. These Marines are the focus of this thesis. In fiscal year 1998, new Marines spent over 2,700 Marine-years in an unproductive status while waiting on their next training schools to convene. Planners at the Marine Corps office of the Deputy Commandant of the Marine Corps for Manpower and Reserve Affairs (M&RA) believe that non-infantry Marines spend an unacceptable amount of time waiting for training between the start of Recruit Training and the completion of their MOS training. This thesis develops two integer linear programs to plan recruiting and MOS school seat scheduling with the primary objective to minimize the time non-infantry enlisted Marines wait for MOS training.

Based on Marine Corps needs for new, trained Marines, M&RA develops personnel requirements and coordinates with the Marine Corps Training and Education Command (TECOM) and the Marine Corps Recruiting Command (MCRC) to satisfy those requirements. M&RA training requirements to TECOM outline how many Marines should be trained by fiscal year and MOS. These requirements are submitted approximately two years prior to execution. TECOM breaks these requests down by four month trimester and forwards the requests to the individual MOS schools. The MOS schools then publish MOS school training schedules approximately 18 months prior to execution to accommodate the training requirements. Approximately one year prior to execution, M&RA develops a recruiting plan, called the Program Plan, that details how many recruits should be recruited by month, gender and enlistment program (enlistment programs outline MOSs that a Marine can train for). M&RA does not currently use published MOS school schedules in the development of the Program Plan.

There are three opportunities for M&RA to significantly improve the coordination of recruiting and training schedules: provide a direct link between the Program Plan and MOS training school schedules; provide training requests to TECOM broken down by

week; and consider published MOS school schedules in the development of the Program Plan.

This thesis proposes two integer linear program models to aid M&RA planners. The first model, Long-term Recruiting and MOS School Scheduler (LRAMS) is for M&RA planners to use two years prior to execution. LRAMS decides weekly: the number of new Marines of each gender and enlistment program to recruit, whether to start a new MOS school course, and the number of Marines to start MOS training by MOS and gender. LRAMS' primary output is a training request by gender, MOS, and convening week. The second model, the Short-term Adjusted Recruiting Model (STAR) is for M&RA planners to use one year prior to execution with published MOS school schedules as input. STAR decides weekly: the number of new Marines of each gender and enlistment program to recruit and the number of Marines to start MOS training by MOS and gender. STAR's primary output is a Program Plan outlining recruiting needs by gender, enlistment program, and recruiting week.

Results using fiscal year 2001 data indicate LRAMS and STAR provide a significant improvement over currently planning methods. LRAMS plans for only 160 total Marine-years for Marines to wait for their first MOS school to convene. STAR uses current (fiscal year 2001) MOS school schedules and plans for only 650 Marine-years waiting. These are significant improvements compared to the 2,700 Marine-years waiting during 1998.

We recommend that LRAMS and STAR be used as described in this thesis to develop MOS school training requests and Program Plans.

I. INTRODUCTION

A. PURPOSE

Non-infantry enlisted Marines (Figure 1) progress through Recruit Training, basic infantry training at Marine Combat Training (MCT), and Military Occupational Specialty (MOS) training before finally reporting to their original unit for duty. These Marines are the focus of this thesis.

Figure 1.   New Marine at Marine Combat Training (MCT). A newly enlisted non-infantry Marine attends Recruit Training and MCT before training for his Military Occupational Specialty (MOS). This thesis develops models to plan recruiting and MOS school schedules for these non-infantry enlisted Marines. [Figure from: Habib 2001]

In fiscal year 1998, new Marines spent over 2,700 Marine-years in an unproductive status while waiting on their next training schools to convene [Goodrum 2001]. Planners at the Marine Corps office of the Deputy Commandant of the Marine Corps for Manpower and Reserve Affairs (M&RA) believe that non-infantry Marines spend an unacceptable amount of time waiting for training between the start of Recruit Training and the completion of their MOS training. Figure 2 summarizes the training required for each new non-infantry Marine. This thesis develops two integer linear

programs to plan recruiting and MOS school seat scheduling with the primary objective to minimize the time non-infantry enlisted Marines wait for MOS training.
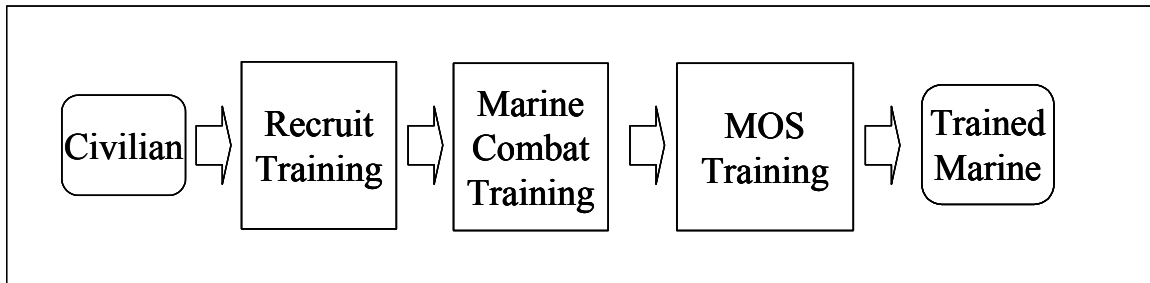
Figure 2.   Initial Training Sequence for Non-infantry Marines.   Enlisted, non-infantry Marines complete Recruit Training, Marine Combat Training, and MOS Training in sequence before being assigned to their first unit as a trained Marine.

B.   CURRENT PLANNING METHOD

Based on Marine Corps needs for new, trained Marines, M&RA develops personnel requirements and coordinates with the Marine Corps Training and Education Command (TECOM) and the Marine Corps Recruiting Command (MCRC) to satisfy those requirements. Figure 3 summarizes how the Marine Corps plans recruiting and MOS training schedules. The following sections give detailed descriptions.
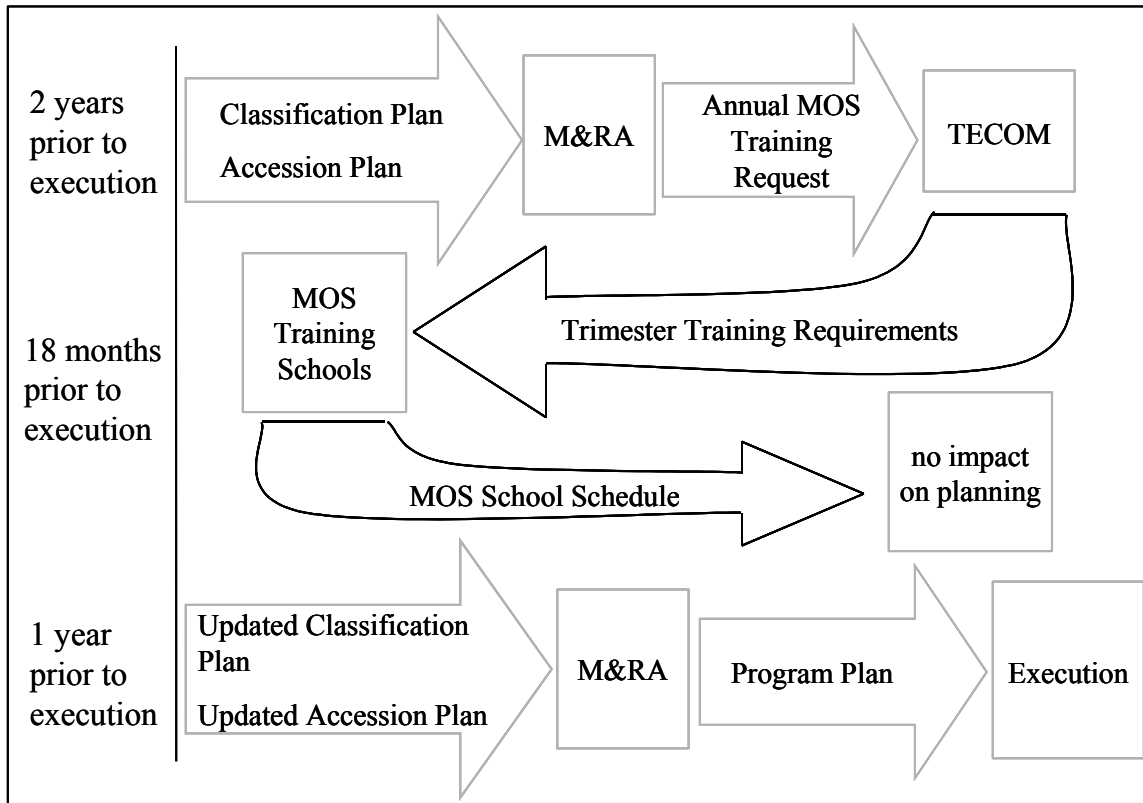
Figure 3.   Current Coordination of Recruiting and MOS Training. Planners at the Marine Corps office of the Deputy Commandant of the Marine Corps for Manpower and Reserve Affairs (M&RA) submit requests for MOS training two years prior to the start of the recruiting year, based on projected requirements for training in each MOS (Classification Plan).   Six months later, the Marine Corps Training and Education Command (TECOM) publishes the MOS training school schedules. One year prior to the recruiting year, M&RA publishes the schedule for recruiting by groups of MOSs (Program Plan) without consideration for the MOS school schedules.

1.   Personnel Requirements

M&RA produces a seven-year recruiting plan called the *Accession Plan* [Klimp 2000] that estimates the number of recruits needed each year to meet *end strength*. End strength is the legislative requirement for the number of Marines in service at the end of the *fiscal year* (October 1 to September 30). M&RA frequently updates the Accession Plan to reflect refined attrition data, legislative changes to required end strength, and any shortages or excesses from a previous year.

M&RA planners also develop a seven-year *Classification Plan* [Bicknell 2000] to plan for preferred MOS and gender proportions. The Classification Plan indicates the

number of new Marines of each gender who graduate from Recruit Training that TECOM should train for each MOS. M&RA planners use a Markov Chain model to develop the Classification Plan [Nguyen 1997]. The Classification Plan is not directly linked to the Accession Plan. Before publishing the Classification Plan, it is scaled so that the total number to classify equals the Accession Plan less anticipated Recruit Training attrition. M&RA updates the Classification Plan annually.

2. MOS Training School Scheduling

Each MOS training school (Figure 4) develops its own schedule of each class start date and available seats two years prior to execution. In the simplest case, Marines attend a single MOS training school that is unique to their intended MOS. In other cases, Marines complete a sequence of multiple training courses to attain their MOS. Marines training for related MOSs often attend a set of common courses before their sequences diverge. TECOM provides MOS training schools with training requirements from the Classification Plan along with historical recruiting data. Each MOS training school develops a training schedule that attempts to fulfill all training requirements while considering personnel and facility limitations.
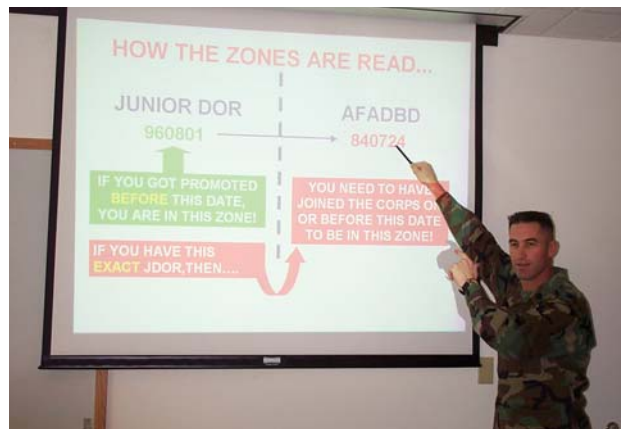
Figure 4.   MOS Training Schools. Constraints such as available classroom space and number of instructors limit the number of times and number of available seats for each MOS course offering. [Figure from: Lund 2000]

TECOM collates the MOS training school schedules and publishes them approximately 18 months prior to execution. In some cases, there are not enough seats in a year to satisfy the annual MOS requirement. In other cases, there are enough seats but the schedule requires students to wait months.

3. Recruiting

High schools are the largest source of new recruits and their graduations are the most significant factor in the recruiting market (Figure 5). For planning purposes, MCRC divides the recruiting year into three trimesters, each containing four consecutive calendar months. MCRC most easily finds qualified recruits immediately after high school graduations in the June to September trimester. Conversely, MCRC has its greatest recruiting difficulties in the February to May trimester immediately prior to graduations.

Figure 5.   Recruiting at America's High Schools. High schools are the greatest source of new recruits, and their graduations are the most significant factor in the recruiting market. [Figure from: Williams 2001]

Using the historical recruiting percentages by month and the Marine Corps requirements in the Classification Plan, planners at M&RA develop the *Program Plan* [Klimp 1999]. The Program Plan describes how many recruits of each gender and *enlistment program* category (set of similar MOSs) MCRC should ship to Recruit Training each month. Recruiters use enlistment programs in *MOS guarantees*. Part of many recruits' enlistment contracts, MOS guarantees ensure recruits training for their selected enlistment programs. Recruiters give MOS guarantees to approximately 70 percent of recruits as an incentive to join the Marine Corps. The M&RA planners publish the Program Plan to outline which MOS guarantees MCRC should offer to perspective recruits each month. M&RA planners first develop the Program Plan two years in advance and update the plan just prior to the execution year.

C. OPPORTUNITIES FOR IMPROVEMENT

There are multiple opportunities for M&RA to improve the coordination of recruiting and training schedules.

1. Provide a Direct Link Between the Program Plan and MOS Training School Schedules

Currently, M&RA does not attempt to directly consider both recruiting and MOS training school constraints to develop the Program Plan and a corresponding MOS school scheduling request. By considering recruiting and training concerns simultaneously, M&RA can produce better plans.

2. Provide Detailed MOS Training Requests to MOS Training Schools

M&RA requests MOS training from TECOM by year, but M&RA planners could use a more detailed Program Plan to determine how many Marines would likely need training by week. If M&RA requested MOS school training by week and TECOM forwarded these requests to the MOS training schools as requirements, the schools would be better able to schedule to meet the actual need.

3. Consider Published MOS Training School Schedules When Updating the Program Plan

Planners at M&RA should use published MOS training school schedules and the numbers of seats available for each class when updating the Program Plan.

D. PROPOSED SYSTEM FOR COORDINATING RECRUITING AND MOS TRAINING

This thesis proposes two models for M&RA planners to use. The first model is an integer linear program called the Long-term Recruiting and MOS School Scheduler (LRAMS) for M&RA planners to use two years prior to execution. LRAMS takes the Accession Plan and Classification Plan as input along with recruiting and MOS training school data. LRAMS minimizes time Marines wait for training between MCT and MOS training school and produces a *MOS school scheduling plan* and the initial Program Plan as output. The MOS training school scheduling plan outlines how many Marines of each gender and intended MOS should begin MOS training each week. The Program Plan outlines the number of recruits of each gender and enlistment program that MCRC should ship to Recruit Training each week.

The second model is an integer linear program called the Short-term Adjusted Recruiting Model (STAR) for M&RA planners to use one year prior to execution. STAR considers published MOS school schedules and class size limitations along with the most recent Accession Plan and Classification Plan. STAR minimizes time Marines wait for training between MCT and MOS training school. STAR's outputs are the updated Program Plan and a schedule of anticipated MOS training school class sizes.

Figure 6 shows how M&RA can use these models to better coordinate the recruiting and training of new Marines.
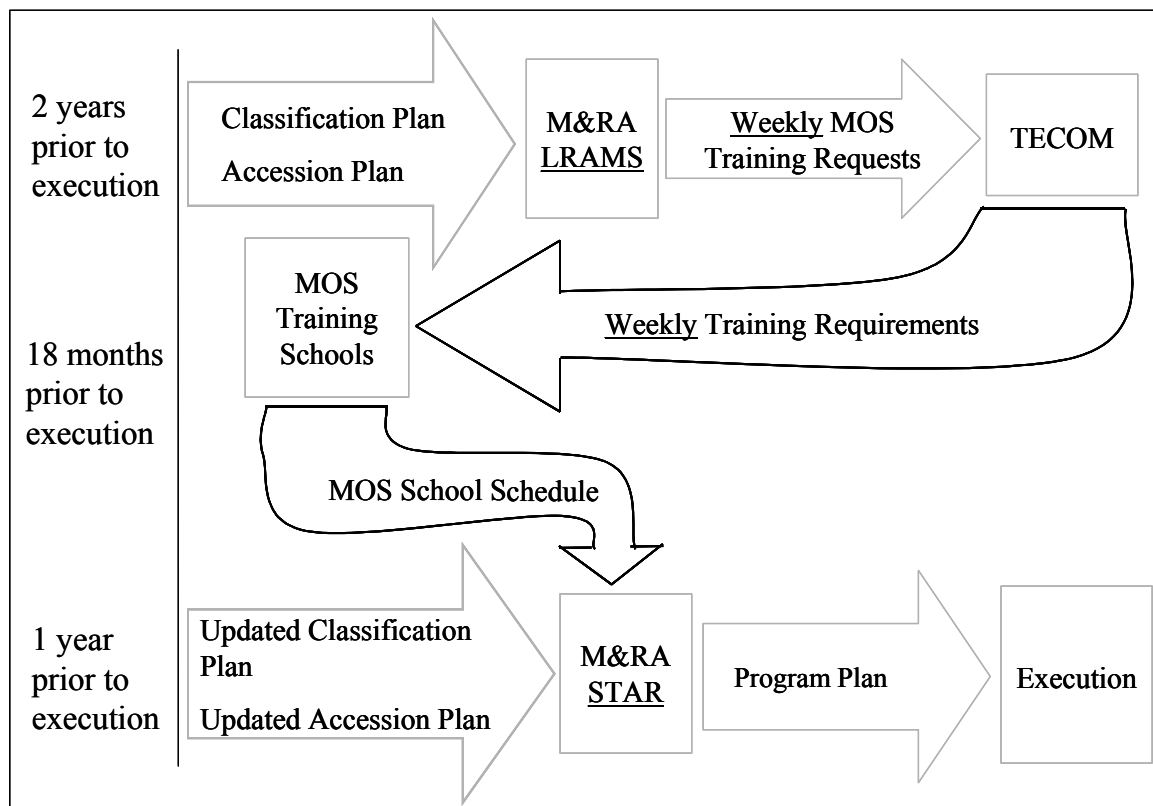
Figure 6.   Improved Coordination of Recruiting and MOS School Training. Providing a direct link between the Program Plan and MOS school schedules, providing detailed training requests to MOS schools, and considering published MOS school schedules are ways to improve the current coordination (Figure 3) of recruiting and MOS school training.

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II.   LITERATURE REVIEW

The operations research literature is rich in manpower models. We categorize existing military manpower research relevant to this thesis into five groups: attrition models, personnel assignment models, manpower system planning models, MOS assignment models, and scheduling models. This chapter highlights a representative sample of recent models in each group and compares them to the models in this thesis.

Attrition models are used to determine accessions requirements. Nguyen [1997] develops a Markov Chain model that considers annual attrition by MOS and years of service to determine how many new Marines are needed in each MOS. Bolton [1998] develops a forecasting model that predicts enlisted attrition based on the breakdown (by pay grade and years of service) of the Marine Corps. These models consider attrition on an annual basis. This thesis also considers attrition (to estimate how many recruits are available for MOS training each week). This thesis differs from the models listed above by using attrition data only as a means of making scheduling decisions, avoiding a more detailed statistical analysis of the attrition rates used.

Personnel assignment models are used to fill billets with qualified personnel. Baumgarten [2000] develops an integer linear program to assign officers to acceptable career paths to enable them to meet their future billet requirements and develop appropriate professional skills. Similarly, Tivnan [1998] develops an integer linear program to assign enlisted Marines to appropriate billets. The primary goal of each of these models is to match individuals to assignments based on selection criteria. Unlike the above models, this thesis assigns new recruits to MOSs based on their enlistment programs while considering both recruiting and training requirements.

Manpower system planning models make simultaneous decisions for accessions, promotions, and separations on an annual basis to maintain appropriate manning levels over many years. Yamada [2000] develops a convex quadratic program to achieve desired manning levels for Army officers over an infinite time horizon. Similarly, Litzenberg [2001] develops an integer linear program to best meet desired manning levels in the Army Reserve and National Guard. Similarly, this thesis makes simultaneous

decisions (for recruiting and training) to produce appropriate manning levels, but does so on a weekly basis to plan for a single year.

MOS assignment models are used to map personnel accessions into MOSs. Grant [2000] develops a model to determine how to assign known quantities of Marine Corps officers in six classes of The Basic School (TBS) into the required quantities of each MOS. In Grant's model, accessions and MOS school schedules are fixed, and all officers are assignable to all MOSs. The model decides how many officers from each class of TBS should be assigned to each MOS in order to minimize time waiting for training for officers after TBS completion. Like Grant's model, this thesis decides how many from each accessed group (Marines recruited in the same week) should be classified into each MOS. This thesis differs from Grant's work because Marines from each enlistment program can only be mapped into a small subset of MOSs, and LRAMS decides recruiting numbers and MOS school convening dates and class sizes.

Hall [1999] develops an integer linear program to produce training schedules for Army Basic Combat Training, One Station Unit Training, and Advanced Individual Training. Hall's model develops the training schedules to accommodate fixed accession numbers and MOSs to minimize the time soldiers wait for training. Like Hall's model, this thesis determines training schedules. Unlike Hall's model, this thesis also determines recruiting schedules and maps accessions in specific enlistment programs into MOSs.

We could not find any existing models that decide recruiting schedules and training schedules simultaneously. In addition to those decisions, this thesis maps accessions from enlistment programs into MOSs.

III. LRAMS

A. MODELING APPROACH

LRAMS' goal is to recommend MOS school training requirements and a Program Plan that minimize the time Marines wait for training between MCT and MOS school. LRAMS includes *penalties* for not satisfying training and recruiting goals. Penalties are piecewise linear approximations of nonlinear, convex penalty functions used to penalize violations of *elastic constraints* (constraints that can be violated, but a violation incurs a penalty). Training requirements output by the model indicate when *student groups* begin training for each MOS. A student group attends MOS training together.

LRAMS uses three types of recruiting data: trimester, monthly, and weekly recruiting limits. MOS training school data take three forms: *class* (an occurrence of a particular MOS course) size limits, limits for time between successive class start dates, and limits on number of annual training classes for each MOS. The first MOS-unique course in each MOS's training sequence forms the basis for one set of class size limits and for delay and frequency restrictions on schedules (recall that in the case of some MOSs, the initial course is shared by other MOSs requiring similar basic skills). Class size limits for the first common course in each MOS are also enforced. For example, the Basic Electronics course is the first course in the MOS training sequences for 11 MOSs including MOS 2811 (Telephone Technician). The maximum class size for the course (30 Marines) limits the total number of students from those 11 MOSs who can begin training in a given week. Marines training for MOS 2811 attend the follow-on course Telephone Switchboard Repair which limits student group sizes to between 15 and 30 Marines. Students in MOS 2811 must begin training between two and six weeks after the previous student group and there must be eight to 26 student groups per year.

B. ASSUMPTIONS

The model uses the following assumptions:

- Marines graduate from MCT on a timeline that is similar to historical results. Some Marines take longer to complete boot camp and MCT than others due to their temporary removal from training or to their repeating portions of training. Others never graduate due to discharge from the service. Data describing the historical distribution of Marines' MCT

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graduation dates based on recruitment date and gender provide the scheduling link between the MOS training school schedule and the Program Plan. Figure 7 illustrates the distribution of MCT graduations for males recruited in week one of the fiscal year. If 100 males are recruited in week one, LRAMS assumes that 13 graduate from MCT in week 17, 38 in week 18, 23 in week 19, 12 in week 20, two each in week 21and 28, and one each in weeks 22, 23, and 25 and seven never graduate.
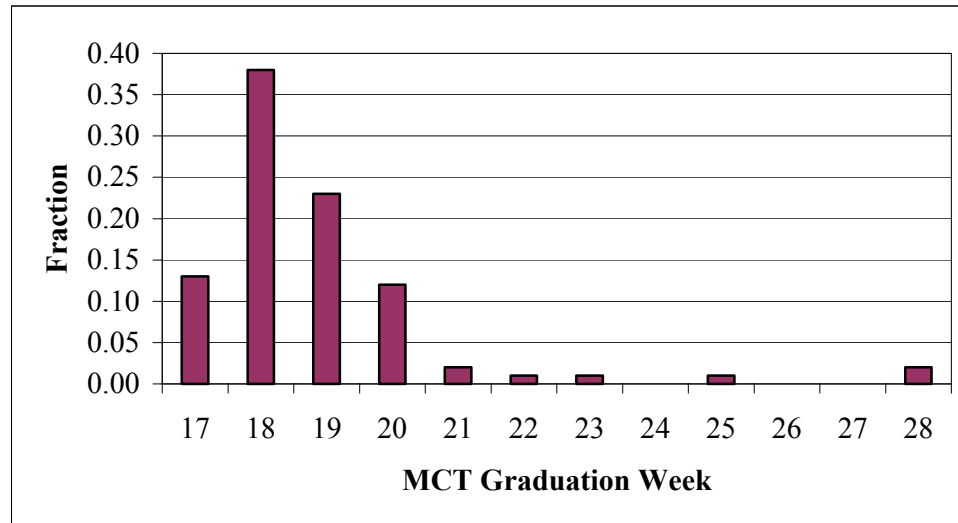
Figure 7.   Distribution of Times to MCT Graduation for Week One Recruits. This histogram shows the historical fraction of male Marines recruited in week one of the fiscal year who graduate from MCT in each of the given weeks. For example, if 100 males are recruited in week one, LRAMS assumes that 13 graduate from MCT in week 17, 38 in week 18, 23 in week 19, 12 in week 20, two each in week 21and 28, and one each in weeks 22, 23, and 25 and seven never graduate.

- All Marines require one week to travel from their MCT school to their MOS school.

- A two-year time horizon is long enough to schedule all Marines for MOS training. LRAMS uses a two-year time horizon but produces a Program Plan for a single recruiting year. Because recruits do not begin their MOS training schools until they complete MCT, months after their recruitment, LRAMS schedules some of the recruits' MOS training after the end of the fiscal year.

- Class size limits for the first common course and the first MOS-unique course in each MOS's training sequence adequately describe the limits for the entire sequence.

- Each common course can be scheduled to accommodate follow-on course timings for all MOSs that require the common course. Minimum and maximum delays between the start dates for successive groups of Marines

are enforced by MOS but not by common course. Minimum and maximum number of student groups per year is also enforced only by MOS.

C. INDICES

c	common course for multiple MOSs
g	gender
m, m'	month
p	enlistment program (e.g. AE, AF)
r	range for piecewise linear penalty function (e.g. 1,2,…)
s	MOS
t	trimester (four month portion of year)
w, w', w''	week

D. SETS

$grpMOS_c$	set of MOSs that attend common course c
inf	set of infantry enlistment programs
$month_t$	set of months that make up trimester t
$MOSgrp_p$	set of MOSs that make up enlistment program p
noninf	set of MOSs that are not part of the infantry
notinf	set of enlistment programs that are not part of the infantry
$week_m$	set of weeks that make up month m

E. DATA

1. Personnel Requirements

acesplan	number of Marines to recruit during the fiscal year according to the accession plan (Marines)
$\underline{classify}_{gs}$, $\overline{classify}_{gs}$	minimum and maximum number of Marines of gender g to classify into MOS s after Recruit Training. (Marines)

2. Recruiting

$\underline{rctfracm}_w$, $\overline{rctfracm}_w$	minimum and maximum fraction of monthly recruits to ship to Recruit Training during week w

$\underline{rctt}_t$, $\overline{rctt}_t$ minimum and maximum number of recruits to ship to Recruit Training during trimester t (Marines)

$\underline{rctfract}_m$, $\overline{rctfract}_m$ minimum and maximum fraction of trimester recruits shipped to Recruit Training during month m

3. MOS Training Schools

$\underline{crs}_{sw}$, $\overline{crs}_{sw}$ minimum and maximum class size for the first unique school in the MOS s training sequence for week w (Marines)

$\overline{grp}_{cw}$ maximum class size for common course c for week w (Marines)

$\underline{delay}_s$, $\overline{delay}_s$ minimum and maximum delay between successive groups of Marines training for MOS s (weeks)

$\underline{numStrt}_s$, $\overline{numStrt}_s$ minimum and maximum number of groups of Marines training for MOS s (groups / year)

note: The model is infeasible if

$$\underline{numStrt}_s > 52 \,/\, \overline{delay}_s \text{ or}$$

$$\overline{numStrt}_s < 52 \,/\, \underline{delay}_s$$

4. Initial Training

$rctfracMCT_{gww'}$ historical fraction of the group of Marines of gender g who ship to Recruit Training during week w (to start training on Monday of week $w + 1$) who graduate from MCT at the end of week w'

5. Penalty

$pCGain_{pr}$ penalty for training more of this year's recruits next year than the number of last year's recruits we train this year for enlistment program p and range r (weeks)

$\underline{pClass}_{grs}$, $\overline{pClass}_{grs}$ penalties for training too few or too many Marines into gender g and MOS s in range r (weeks)

$\underline{pClassp}_{gpr}$, $\overline{pClassp}_{gpr}$ penalties for recruiting too few or too many Marines into gender g and program p in range r (weeks)

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$\overline{\text{pCourse}}_{cmr}$ penalties for violating the maximum class size for common course c during month m in range r (weeks)

$\underline{\text{pProp}}_{mr}$, $\overline{\text{pProp}}_{mr}$ penalties for shipping too few or too many recruits to Recruit Training (as a proportion of the trimester) during month m in range r (weeks)

$\underline{\text{pRct}}_{rt}$, $\overline{\text{pRct}}_{rt}$ penalty for violating the minimum or maximum recruiting limits during trimester t in range r (weeks)

$\underline{\text{pSeat}}_{mrs}$, $\overline{\text{pSeat}}_{mrs}$ penalties for violating the minimum or maximum group sizes for the first unique school in the MOS s training sequence during month m in range r (weeks)

pWait_{mpr} penalty for causing a Marine of enlistment program p to wait 1 week during month m to begin MOS training in range r

6. Variable Bounds

mCGain_{pr} upper bound for increased number of this year's recruits to train next year over the number of last year's recruits we train this year for enlistment program p and range r (Marines)

$\underline{\text{mClass}}_{grs}$, $\overline{\text{mClass}}_{grs}$ upper bound for violations of minimum and maximum classification limits for gender g, MOS s, and range r (Marines)

$\underline{\text{mClassp}}_{gpr}$, $\overline{\text{mClassp}}_{gpr}$ upper bound for violations of minimum and maximum classification limits for gender g, enlistment program p, and range r (Marines)

$\overline{\text{mCourse}}_{crm}$ upper bound for violations of the maximum class size limit for common course c, month m and range r (Marines)

$\underline{\text{mProp}}_{mr}$, $\overline{\text{mProp}}_{mr}$ upper bound for deviations from historical trimester recruiting fractions for month m and range r (Marines)

$\underline{mRct}_{rt}$, $\overline{mRct}_{rt}$	upper bound for violation of minimum and maximum recruiting limits for trimester t and range r (Marines)
$\underline{mSeat}_{mrs}$, $\overline{mSeat}_{mrs}$	upper bound for violation of minimum and maximum class sizes for MOS s in month m and range r (Marines)
$mWait_{gmpr}$	upper bound for the number of Marines of gender g, enlistment program p, and range r who are required to wait for at least one week in month m to begin their first MOS training school (Marines)
$\underline{rctw}_{gp}$, $\overline{rctw}_{gp}$	lower and upper bounds for the number of recruits per week of gender g and enlistment program p (Marines)

7.   Initial Conditions

$\overline{cCourse}_{cw}$	number of Marines from the previous year's recruiting class outside of the maximum class size who begin common course c at the beginning of week w (Marines)
$cMCTgrad_{gpw}$	number of Marines of gender g and enlistment program p from the previous year's recruiting class expected to graduate from MCT in week w (Marines)
$\underline{cSeat}_{sw}$, $\overline{cSeat}_{sw}$	number of Marines from the previous year's recruiting class outside of the minimum or maximum class size who begin MOS school training for MOS s at the beginning of week w (Marines)
$cTrain_{gsw}$	number of Marines of gender g from the previous year's recruiting class scheduled to begin training for MOS s in week w (Marines)
$cWait_{gprw}$	number of Marines of gender g and enlistment program p from the previous year's recruiting class waiting for at least one week to begin MOS training in week w and range r (Marines)
$eStart_s$	the earliest available start week for groups of Marines training for MOS s

F. VARIABLES

1. Binary

$START_{sw}$ — 1 if a group of Marines begins training for MOS s at the beginning of week w, 0 otherwise

2. Positive

$CGAIN_{pr}$ — number of recruits to train next year over the number of last year's recruits we train this year for enlistment program p and range r (Marines)

$\underline{CLASS}_{grs}$, $\overline{CLASS}_{grs}$ — number of Marines in range r of gender g trained into MOS s outside of the minimum or maximum classification limits (Marines)

$\underline{CLASSP}_{gpr}$, $\overline{CLASSP}_{gpr}$ — number of Marines in range r of gender g recruited into program p outside of the minimum or maximum classification limits (Marines)

$\overline{COURSE}_{crw}$ — number of Marines in range r outside of the maximum class size who begin training for common course c at the beginning of week w (Marines)

$\underline{PROP}_{mr}$, $\overline{PROP}_{mr}$ — number of Marine recruits in range r to ship to Recruit Training during month m outside of the minimum or maximum trimester proportion limit (Marines)

$\underline{RCT}_{rt}$, $\overline{RCT}_{rt}$ — number of Marines to recruit in range r during trimester t outside of the minimum or maximum recruiting limits (Marines)

$RECRUIT_{gpw}$ — number of Marine recruits of gender g and program p to ship to Recruit Training during week w (to start training at the beginning of week $w + 1$) (Marines)

$\underline{SEAT}_{rsw}$, $\overline{SEAT}_{rsw}$ — number of Marines in range r outside of the minimum or maximum class size who begin training for MOS s at the beginning of week w (Marines)

$TRAIN_{gsw}$ — number of Marines of gender g to begin training for MOS s at the beginning of week w (Marines)

$WAIT_{gprw}$ — the anticipated number of Marines in range r of gender g and enlistment program p who will wait at least one week during week w for the start of their MOS school class (Marine-weeks)

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G. FORMULATION

1. Objective Function

minimize Z $\hspace{4cm}$ (in Marine-weeks units)

$$Z = \sum_{gmpr,\,w\in\text{month}_m} \text{pWait}_{mpr}\ \text{WAIT}_{gprw} +$$

$$\sum_{mrs,\,w\in\text{month}_m} (\overline{\text{pSeat}}_{mrs}\ \overline{\text{SEAT}}_{rsw} + \underline{\text{pSeat}}_{mrs}\ \underline{\text{SEAT}}_{rsw}) +$$

$$\sum_{cmr,\,w\in\text{month}_m} \overline{\text{pCourse}}_{cmr}\ \overline{\text{COURSE}}_{crw} + \sum_{rt}(\overline{\text{pRct}}_{rt}\ \overline{\text{RCT}}_{rt} + \underline{\text{pRct}}_{rt}\ \underline{\text{RCT}}_{rt}) +$$

$$\sum_{mr}(\overline{\text{pProp}}_{mr}\ \overline{\text{PROP}}_{mr} + \underline{\text{pProp}}_{mr}\ \underline{\text{PROP}}_{mr}) +$$

$$\sum_{grs}(\overline{\text{pClass}}_{grs}\ \overline{\text{CLASS}}_{grs} + \underline{\text{pClass}}_{grs}\ \underline{\text{CLASS}}_{grs}) +$$

$$\sum_{gpr}(\overline{\text{pClassp}}_{gpr}\ \overline{\text{CLASSP}}_{gpr} + \underline{\text{pClassp}}_{gpr}\ \underline{\text{CLASSP}}_{gpr}) +$$

$$\sum_{pr}\text{pCGain}_{pr}\ \text{CGAIN}_{pr} \hspace{5cm} \text{(L1)}$$

2. Constraints

$$\text{cMCTgrad}_{gpw} + \sum_{w'}\text{rctfracMCT}_{gw'w}\ \text{RECRUIT}_{gpw'} + \sum_{r}\text{WAIT}_{gprw+1} =$$

$$\sum_{s\in\text{MOSgrp}_p}\text{TRAIN}_{gsw+2} + \sum_{r}\text{WAIT}_{gprw+2} \hspace{1cm} \forall g, p\in\text{notinf},w \hspace{0.5cm} \text{(L2)}$$

$$\sum_{gp,\,m\in\text{month}_t,\,w\in\text{week}_m}\text{RECRUIT}_{gpw} \le \overline{\text{rctt}}_t + \sum_{r}\overline{\text{RCT}}_{rt} \hspace{1cm} \forall t \hspace{1cm} \text{(L3)}$$

$$\sum_{gp,\,m\in\text{month}_t,\,w\in\text{week}_m}\text{RECRUIT}_{gpw} \ge \underline{\text{rctt}}_t - \sum_{r}\underline{\text{RCT}}_{rt} \hspace{1cm} \forall t \hspace{1cm} \text{(L4)}$$

$$\sum_{gp,\,w\in\text{week}_m}\text{RECRUIT}_{gpw} \le$$

$$\overline{\text{rctfract}}_m\sum_{gp,\,m'\in\text{month}_t,\,w\in\text{week}_{m'}}\text{RECRUIT}_{gpw} + \sum_{r}\overline{\text{PROP}}_{mr} \hspace{1cm} \forall t, m\in\text{month}_t \hspace{0.5cm} \text{(L5)}$$

$$\sum_{gp,\,w\in\text{week}_m}\text{RECRUIT}_{gpw} \ge$$

$$\underline{\text{rctfract}}_m\sum_{gp,\,m'\in\text{month}_t,\,w\in\text{week}_{m'}}\text{RECRUIT}_{gpw} - \sum_{r}\underline{\text{PROP}}_{mr} \hspace{1cm} \forall t, m\in\text{month}_t \hspace{0.5cm} \text{(L6)}$$

$$\text{RECRUIT}_{gpw} \le \sum_{w'\in\text{week}_m}\overline{\text{rctfracm}}_w\text{RECRUIT}_{gpw'} \hspace{1cm} \forall gmp, w\in\text{week}_m \hspace{0.5cm} \text{(L7)}$$

$$\text{RECRUIT}_{gpw} \ge \sum_{w'\in\text{week}_m}\underline{\text{rctfracm}}_w\text{RECRUIT}_{gpw'} \hspace{1cm} \forall gmp, w\in\text{week}_m \hspace{0.5cm} \text{(L8)}$$

$$\sum_{g}\text{TRAIN}_{gsw} \le \overline{\text{crs}}_{sw}\text{START}_{sw} + \sum_{r}\overline{\text{SEAT}}_{rsw} \hspace{1cm} \forall s\in\text{noninf}, w\ge 3 \hspace{0.5cm} \text{(L9)}$$

$$\sum_{g,s \in \text{grpMOS}_c} \text{TRAIN}_{gsw} \leq \overline{\text{grp}}_{cw} + \sum_r \overline{\text{COURSE}}_{crw} \qquad \forall c, w \geq 3 \qquad \text{(L10)}$$

$$\sum_g \text{TRAIN}_{gsw} \geq \underline{\text{crs}}_{sw} \text{START}_{sw} - \sum_r \underline{\text{SEAT}}_{rsw} \qquad \forall s \in \text{noninf}, w \geq 3 \qquad \text{(L11)}$$

$$\sum_g \text{TRAIN}_{gsw} \leq 5\overline{\text{crs}}_{sw} \text{START}_{sw} \qquad \forall s \in \text{noninf}, w \geq 3 \qquad \text{(L12)}$$

$$\sum_{g,s \in \text{MOSgrp}_p, w} \text{TRAIN}_{gsw} = \sum_g \text{cWait}_{gp2} + \sum_{gw} \text{cMCTgrad}_{gpw} +$$
$$\sum_{g,s \in \text{MOSgrp}_p, w} \text{cTrain}_{gsw} + \sum_{gww'} \text{rctfracMCT}_{gww'} \ \text{RECRUIT}_{gpw} \qquad \forall p \in \text{notinf} \qquad \text{(L13)}$$

$$\sum_{g,s \in \text{MOSgrp}_p, w>52} \text{TRAIN}_{gsw} \leq \sum_g \text{cWait}_{gp2} + \sum_{gw} \text{cMCTgrad}_{gpw} +$$
$$\sum_{g,s \in \text{MOSgrp}_p, w} \text{cTrain}_{gsw} + \sum_r \text{CGAIN}_{pr} \qquad \forall p \in \text{notinf} \qquad \text{(L14)}$$

$$\sum_{w'=w}^{w+\underline{\text{delay}}_s-1} \text{START}_{sw} \leq 1 \qquad \forall s \in \text{noninf},$$
$$w \geq \max\{\text{eStart}_s, 3\} \qquad \text{(L15)}$$

$$\sum_{w'=w}^{w+\overline{\text{delay}}_s-1} \text{START}_{sw} \geq 1 \qquad \forall s \in \text{noninf},$$
$$\max\{\text{eStart}_s, 3\} \leq w \leq 52 \qquad \text{(L16)}$$

$$\sum_{w \leq 52} \text{START}_{sw} \leq \overline{\text{numStrt}}_s \qquad \forall s \in \text{noninf} \qquad \text{(L17)}$$

$$\sum_{w \leq 52} \text{START}_{sw} \geq \underline{\text{numStrt}}_s \qquad \forall s \in \text{noninf} \qquad \text{(L18)}$$

$$\sum_{gpw} \text{RECRUIT}_{gpw} = \text{acesplan} \qquad \text{(L19)}$$

$$\sum_{w \leq 52} \text{TRAIN}_{gsw} \leq \overline{\text{classify}}_{gs} + \sum_r \overline{\text{CLASS}}_{grs} \qquad \forall g, s \in \text{noninf} \qquad \text{(L20)}$$

$$\sum_{w \leq 52} \text{TRAIN}_{gsw} \geq \underline{\text{classify}}_{gs} - \sum_r \underline{\text{CLASS}}_{grs} \qquad \forall g, s \in \text{noninf} \qquad \text{(L21)}$$

$$\sum_{ww'} \text{rctfracMCT}_{gw'w} \ \text{RECRUIT}_{gpw'} \leq \sum_{s \in \text{MOSgrp}_p} \overline{\text{classify}}_{gs} +$$
$$\sum_r \overline{\text{CLASSP}}_{gpr} \qquad \forall g, p \qquad \text{(L22)}$$

$$\sum_{ww'} \text{rctfracMCT}_{gw'w} \ \text{RECRUIT}_{gpw'} \geq \sum_{s \in \text{MOSgrp}_p} \underline{\text{classify}}_{gs} -$$
$$\sum_r \underline{\text{CLASSP}}_{gpr} \qquad \forall g, p \qquad \text{(L23)}$$

3. Variable Bounds

$0 \leq \text{CGAIN}_{pr} \leq \text{mCGain}_{pr} \ \forall pr$;

$$0 \le \overline{CLASS}_{grs} \le \overline{mClass}_{grs} \quad \forall grs ;$$

$$0 \le \underline{CLASS}_{grs} \le \underline{mClass}_{grs} \quad \forall grs ;$$

$$0 \le \overline{CLASSP}_{gpr} \le \overline{mClassp}_{gpr} \quad \forall gpr ;$$

$$0 \le \underline{CLASSP}_{gpr} \le \underline{mClassp}_{gpr} \quad \forall gpr ;$$

$$0 \le \overline{COURSE}_{crw} \le \overline{mCourse}_{crw} \quad \forall cr, w \ge 3 ;$$

$$\overline{COURSE}_{crw} = \overline{cCourse}_{crw} \quad \forall cr, w < 3 ;$$

$$0 \le \overline{PROP}_{mr} \le \overline{mProp}_{mr} \quad \forall mr ;$$

$$0 \le \underline{PROP}_{mr} \le \underline{mProp}_{mr} \quad \forall mr ;$$

$$0 \le \overline{RCT}_{rt} \le \overline{mRct}_{rt} \quad \forall rt ;$$

$$0 \le \underline{RCT}_{rt} \le \overline{mRct}_{rt} \quad \forall rt ;$$

$$\underline{rctw}_{gp} \le RECRUIT_{gpw} \le \overline{rctw}_{gp} \quad \forall gp, w \le 52 ;$$

$$RECRUIT_{gpw} = 0 \; \forall gp, w > 52 ;$$

$$0 \le \overline{SEAT}_{rsw} \le \overline{mSeat}_{rsw} \quad \forall rs, w \ge 3 ;$$

$$\overline{SEAT}_{rsw} = \overline{cSeat}_{rsw} \quad \forall rs, w < 3 ;$$

$$0 \le \underline{SEAT}_{rsw} \le \underline{mSeat}_{rsw} \quad \forall rs, w \ge 3 ;$$

$$\underline{SEAT}_{rsw} = \underline{cSeat}_{rsw} \quad \forall rs, w < 3 ;$$

$$START_{sw} \in \{0,1\} \; \forall s, w \ge eStart_s ;$$

$$START_{sw} = 0 \; \forall s, w < eStart_s ;$$

$$0 \le TRAIN_{gsw} \quad \forall gs, w \ge 3 ;$$

$$TRAIN_{gsw} = cTrain_{gsw} \quad \forall gs, w < 3 ;$$

$$TRAIN_{gsw} = 0 \text{ for unauthorized } g, s \text{ combinations} ;$$

$$0 \le WAIT_{gprw} \le mWait_{gprw} \quad \forall gpr, w \ge 3 ;$$

$$WAIT_{gprw} = cWait_{gprw} \quad \forall gpr, w < 3 ; \tag{L24}$$

H.   DISCUSSION

The objective function, Equation (L1), minimizes a weighted function of the time Marines wait for training between MCT and the start of their MOS training and the violation of recruiting and MOS school capacity constraints.

Equations (L2) are balance constraints that ensure that all Marines who are awaiting MOS training in a given week or who complete MCT the following week either begin MOS training or await MOS training in two weeks (recall assumption: one week travel between MCT and first MOS school).

Equations (L3) and (L4) count and record violations of the maximum and minimum number of recruits to be shipped to Recruit Training in a trimester.

Equations (L5) and (L6) count and record violations of maximum and minimum monthly fractions of trimester recruiting.

Equations (L7) and (L8) limit the maximum and minimum weekly fractions of monthly recruiting.

Equations (L9), (L10), and (L11) count and record violations of the maximum and minimum number of Marines to be assigned to one class of a MOS training school.

Equations (L12) ensure that Marines only attend scheduled MOS school classes. The value five, used on the right-hand side of the equation, is large enough to bound the left-hand side value of any feasible solution.

Equations (L13) ensure that all Marines who graduate from MCT are scheduled for MOS training.

Equations (L14) ensure that large numbers of Marines are not delayed in training unnecessarily.

Equations (L15) and (L16) enforce minimum and maximum delays between successive MOS school class starts.

Equations (L17) and (L18) enforce the maximum and minimum number of MOS school classes.

Equation (L19) ensures that the Accession Plan is executed to meet required Marine Corps end strength.

Equations (L20) and (L21) ensure that the numbers of non-infantry Marines who receive MOS training match the numbers represented in the Classification Plan with respect to gender and MOS.

Equations (L22) and (L23) ensure that the expected numbers of initial training graduates match the numbers represented in the Classification Plan with respect to gender and enlistment program (shapes recruiting breakdown by gender and enlistment program).

Equations (L24) bound variables.

I. DERIVED DATA

The following data are derived:

1. Recruiting

$$\underline{rctfract}_m = (1 - \underline{ratiodev}_m)trirctratio_m$$

$$\overline{rctfract}_m = (1 + \overline{ratiodev}_m)trirctratio_m$$

where

$\underline{ratiodev}_m$, $\overline{ratiodev}_m$	allowed fraction below and above the historical trimester fraction of recruits shipped to Recruit Training during month m
$trirctratio_m$	trimester fraction of recruits sent to Recruit Training during month m

2. MOS and Gender Shaping

$$\underline{classify}_{gs} = (1 - \underline{classdev}_{gs})clasplan_{gs}$$

$$\overline{classify}_{gs} = (1 + \overline{classdev}_{gs})clasplan_{gs}$$

where

$clasplan_{gs}$	number of Marines of gender g to classify into MOS s after Recruit Training based on the Classification Plan (Marines)
$\underline{classdev}_{gs}$, $\overline{classdev}_{gs}$	allowable fraction below and above the classification requirements of the Classification Plan for gender g and MOS s

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3. Variable Bounds

$$\underline{rctw}_{gp} = \underline{rctrat}_{gp} \; acesplan \sum_{s \in MOSgrp_p} clasplan_{gs} / (52 \sum_{gs} clasplan_{gs})$$

$$\overline{rctw}_{gp} = \overline{rctrat}_{gp} \; acesplan \sum_{s \in MOSgrp_p} clasplan_{gs} / (52 \sum_{gs} clasplan_{gs})$$

where

$\underline{rctrat}_{gp}$, $\overline{rctrat}_{gp}$ allowable fraction below and above the equal share of accession for each week scaled by the Classification Plan proportion for gender g and enlistment program p

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IV. STAR

A. MODELING APPROACH

STAR optimally adjusts the Program Plan to match published MOS school schedules and associated quotas in order to minimize time Marines wait for training between MCT and MOS school. STAR is identical to LRAMS except that the dates that MOS school classes begin are fixed in the first year of the model and stiffer penalties are accrued for violating the published class size limits.

Most of the data and equations in STAR are the same as those in LRAMS. The differences reflect the knowledge of MOS class schedules and the associated quotas for each class. The binary variables $START_{sw}$, minimum and maximum class sizes, and associated penalties used in LRAMS are not relevant in the first year in STAR and are therefore replaced in that interval by $convene_{sw}$, $\overline{gquota}_{cw}$, $\underline{quota}_{sw}$, $\overline{quota}_{sw}$, $\overline{pGQuota}_{cmr}$, $\underline{pQuota}_{mrs}$, and $\overline{pQuota}_{mrs}$, defined below. The data, $eStart_s$, are redefined to reflect the earliest allowable MOS school variable start date being in the second year. Equations (L1), (L9), (L10), (L11), (L12), (L16), (L17), and (L18) from LRAMS are not in STAR. The STAR data and equations that are not in LRAMS are shown below.

B. DATA

1. MOS School

$convene_{sw}$	1 if Marines training for MOS s are authorized to begin MOS school training in week w, 0 otherwise for $w \leq 52$
$gconvene_{cw}$	1 if common course c has a class that starts in week w, 0 otherwise for $w \leq 52$
$\overline{gquota}_{cw}$	maximum number of seats available for common course c class that starts in week w (Marines)
$\underline{quota}_{sw}$, $\overline{quota}_{sw}$	minimum and maximum number of Marines authorized to begin training for MOS s in week w (Marines)
$eStart_s$	the earliest available MOS training start week for MOS s Marines after week 52 (derived from

mindelay$_s$ and the latest convene$_{sw}$ of the current year)

2. Penalty

$\overline{\text{pGQuota}}_{cmr}$ penalties for violating the published maximum class size for a common course c class during month m for violations in range r (weeks)

$\underline{\text{pQuota}}_{mrs}$, $\overline{\text{pQuota}}_{mrs}$ penalties for violating the published minimum or maximum goup sizes for the first unique school in the MOS s training sequence during month m in range r (weeks)

C. FORMULATION

1. Objective Function

minimize Z   (in Marine-weeks units)

$$Z = \sum_{gmpr,\,w\in \text{month}_m} \text{pWait}_{mpr}\, \text{WAIT}_{gprw} +$$

$$\sum_{mrs,\,w\in \text{month}_m} \left[(\overline{\text{pSeat}}_{mrs} + \overline{\text{pQuota}}_{mrs})\overline{\text{SEAT}}_{rsw} + (\underline{\text{pSeat}}_{mrs} + \underline{\text{pQuota}}_{mrs})\underline{\text{SEAT}}_{rsw} \right] +$$

$$\sum_{cmr,\,w\in \text{month}_m} (\overline{\text{pCourse}}_{cmr} + \overline{\text{pGQuota}}_{cmr})\overline{\text{COURSE}}_{crw} +$$

$$\sum_{rt} (\overline{\text{pRct}}_{rt}\,\overline{\text{RCT}}_{rt} + \underline{\text{pRct}}_{rt}\,\underline{\text{RCT}}_{rt}) +$$

$$\sum_{mr} (\overline{\text{pProp}}_{mr}\,\overline{\text{PROP}}_{mr} + \underline{\text{pProp}}_{mr}\,\underline{\text{PROP}}_{mr}) +$$

$$\sum_{grs} (\overline{\text{pClass}}_{grs}\,\overline{\text{CLASS}}_{grs} + \underline{\text{pClass}}_{grs}\,\underline{\text{CLASS}}_{grs}) +$$

$$\sum_{gpr} (\overline{\text{pClassp}}_{gpr}\,\overline{\text{CLASSP}}_{gpr} + \underline{\text{pClassp}}_{gpr}\,\underline{\text{CLASSP}}_{gpr}) +$$

$$\sum_{pr} \text{pCGain}_{pr}\,\text{CGAIN}_{pr} \tag{S1}$$

2. Constraints

LRAMS equations (L2) to (L8), (L13) to (L15), and (L19) to (L24) are also used in STAR. (L15) is fundamentally altered by the redefining of eStart$_s$.

$$\sum_g \text{TRAIN}_{gsw} \le \overline{\text{quota}}_{sw} \text{convene}_{sw} + \sum_r \overline{\text{SEAT}}_{rsw} \qquad \forall s \in \text{noninf}, w \le 52 \quad \text{(S2)}$$

$$\sum_g \text{TRAIN}_{gsw} \le \overline{\text{crs}}_{sw} \text{START}_{sw} + \sum_r \overline{\text{SEAT}}_{rsw} \qquad \forall s \in \text{noninf}, w > 52 \quad \text{(S3)}$$

$$\sum_{g, s \in \text{grpMOS}_c} \text{TRAIN}_{gsw} \le \overline{\text{gquota}}_{cw} \text{gconvene}_{cw} + \sum_r \overline{\text{COURSE}}_{crw} \quad \forall c, w \le 52 \quad \text{(S4)}$$

$$\sum_{g, s \in \text{grpMOS}_c} \text{TRAIN}_{gsw} \le \overline{\text{grp}}_{cw} + \sum_r \overline{\text{COURSE}}_{crw} \qquad \forall c, w > 52 \quad \text{(S5)}$$

$$\sum_g \text{TRAIN}_{gsw} \ge \underline{\text{quota}}_{sw} \text{convene}_{sw} - \sum_r \underline{\text{SEAT}}_{rsw} \qquad \forall s \in \text{noninf}, w \le 52 \quad \text{(S6)}$$

$$\sum_g \text{TRAIN}_{gsw} \ge \underline{\text{crs}}_{sw} \text{START}_{sw} - \sum_r \underline{\text{SEAT}}_{rsw} \qquad \forall s \in \text{noninf}, w > 52 \quad \text{(S7)}$$

$$\sum_g \text{TRAIN}_{gsw} \le \text{acesplan convene}_{sw} \qquad \forall s \in \text{noninf}, w \le 52 \quad \text{(S8)}$$

$$\sum_g \text{TRAIN}_{gsw} \le 3\overline{\text{crs}}_{sw} \text{START}_{sw} \qquad \forall s \in \text{noninf}, w > 52 \quad \text{(S9)}$$

D. DISCUSSION

As stated above, several changes are made from LRAMS to STAR. Equation (S1) replaces equation (L1) to allow more significant penalties for violating known MOS school class quotas than those for violating estimated MOS school class size limits. Several changes are made because quotas for each MOS school class are known in the first year. Equations (S2) and (S3) replace equation (L9). Equations (S4) and (S5) replace equation (L10). Equations (S6) and (S7) replace equation (L11). Equations (S8) and (S9) replace equation (L12). Equations (L16), (L17), and (L18) are not appropriate in STAR.

The objective function, Equation (S1), minimizes a weighted function of the time Marines wait for training between MCT and MOS school and the violation of recruiting and MOS school capacity constraints.

Equations (S2) through (S7) count and record scheduled violations of the maximum and minimum number of Marines to be assigned to one class of a MOS school or common course.

Equations (S8) and (S9) ensure that Marines only attend scheduled MOS school classes. The value three, used on the right-hand side of equation (S9), is large enough to bound the left-hand side of any feasible solution.

E.   DERIVED DATA

The earliest available MOS training start week for MOS s after week 52 is derived from the minimum delay between successive MOS training school classes and the latest scheduled convene date.

$$\text{eStart}_s = \max\{w|\ \text{convene}_{sw} = 1\} + \underline{\text{delay}}_s \qquad\qquad \forall s$$

F.   MODEL INITIAL CONDITIONS AND INTERACTIONS

Results from the second year of a STAR output predict future execution and provide the initial data for the following year's LRAMS and STAR models.   For example, STAR is used early in fiscal year 2001 to plan for recruiting and training for Marines recruited in fiscal year 2002. Marines recruited in the last part of fiscal year 2002 would be trained in 2003 and would populate the TRAIN_{gsw} and WAIT_{gprw} variables for $w > 52$ as well as serving to predict MCT graduations in the first part of fiscal year 2003. This information is used to populate the parameter cMCTgrad_{gpw} that serves as initial data for the LRAMS and STAR models for fiscal year 2003 (run in fiscal years 2001 and 2002 respectively). Calculation methods are shown below.

For all common courses c and weeks $w < 3$, $\overline{\text{cCourse}}_{cw}$ of this year's models equals the sum over all ranges r of $\overline{\text{COURSE}}_{crw+52}$ of last year's STAR model.

For all genders g, enlistment programs p and weeks $w < 53$, cMCTgrad_{gpw} of this year's models equals the sum over all MOSs s that are elements of MOSgrp_p of TRAIN_{gsw+54} added to the sum over all ranges r of $\text{WAIT}_{gprw+54}$ minus the sum over all ranges r of $\text{WAIT}_{gprw+53}$ of last year's STAR model.

For all MOSs s and weeks $w < 3$, $\overline{\text{cSeat}}_{sw}$ of this year's models equals the sum over all ranges r of $\overline{\text{SEAT}}_{rsw+52}$ of last year's STAR model.

For all MOSs s and weeks $w < 3$, $\underline{\text{cSeat}}_{sw}$ of this year's models equals the sum over all ranges r of $\underline{\text{SEAT}}_{rsw+52}$ of last year's STAR model.

For all genders g, MOSs s and weeks $w < 3$, cTrain_{gsw} of this year's models equals TRAIN_{gsw+52} of last year's STAR model.

For all genders g, enlistment programs p and weeks $w < 3$, cWait$_{gprw}$ of this year's models equals WAIT$_{gprw+52}$ of last year's STAR model.

For all MOSs s, eStart$_s$ of this year's LRAMS model equals the $\underline{delay}_s$ minus 52 added to the w of the latest MOS school convene date in the first year of last year's STAR model.

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V. PENALTIES

A. DEVELOPMENT

The penalty values in both LRAMS and STAR objective functions are the product of a penalty weight, a discount factor (if appropriate), and a nonlinear factor, NLF_r, (used to penalize at a greater rate per unit as violations grow). Variables associated with violations of elastic constraints, use a changing slope for the penalty per unit so that the summation over all ranges of the product of the slope and the variable approximates the value of the square of the sum of the variable over all ranges.

The discount factor ensures that earlier violations are penalized heavier than later violations. This discounting reflects the relative likelihood of early and late decisions being carried out as planned during execution. Although the model considers a two-year time window to allow for the scheduling of MOS training for all of the first year recruits, only the first 52 weeks of schedules are used directly. Decision-makers do not use scheduling decisions made by either model after the first 52 weeks under consideration. For this reason, the discount factors have significantly smaller values in the second year of the models.

The WAIT variable, not associated with violating elastic constraints, uses a constant slope of one. Other penalty weights compare the significance of violations of elastic constraints against the significance of a Marine waiting that number of weeks before beginning his or her MOS school. For example, the assignment of a penalty weight of 52 for classifying too few male Marines into the 0311 MOS means that the decision-maker considers a Marine waiting 52 weeks for the start of his or her MOS school to be of equal concern as allowing the Marine Corps to train one too few male Marines for duty in the 0311 MOS.

Decision-makers can develop penalty weights for constraint violations relatively easily in a two-step process. First, the decision-maker judges the significance of the constraint violation on a scale from zero to one. Next, the decision-maker determines the logical upper bound for the penalty weight. The penalty weight is the product of the significance and the upper bound on the number of weeks one Marine's wait time could

change due to a violation of the associated constraint. For instance, the weight associated with the variable $\overline{RCT}$ penalizes violations of maximum trimester recruiting limits. Because there are approximately 18 weeks in a trimester, the upper bound for the penalty weight associated with the constraint violation is 18. If the decision-maker determines the significance of this type of violation to be 0.3, the resulting penalty weight is 5.4. Table 1 outlines the author's development of the penalty weights used in this study.

	Upper Bound	Significance of Associated Constraint Violations	Penalty Weight
pCGain	52	1.00	52.00
$\overline{pClass}$	52	1.00	52.00
pClass	52	1.00	52.00
$\overline{pClassp}$	52	1.00	52.00
pClassp	52	1.00	52.00
$\overline{pCourse}$	5	0.30	1.50
$\overline{pGQuota}$	5	0.40	2.00
$\overline{pProp}$	5	0.15	0.75
pProp	5	0.05	0.25
$\overline{pQuota}$	5	0.40	2.00
pQuota	5	0.15	0.75
$\overline{pRct}$	18	0.35	6.30
pRct	18	0.25	4.50
$\overline{pSeat}$	5	0.30	1.50
pSeat	5	0.20	1.00

Table 1.   Penalty Weight Development. Penalty weights are the product of a significance level assigned by the decision-maker and a logical upper bound on the impact in a Marine's waiting time that can be caused by the associated constraint violation.

B.   MANAGERIAL INTERPRETATIONS ASSOCIATED WITH PENALTIES

1.   Comparing Constraint Violations with Time Marines Wait for MOS Training

Penalty Weights describe the decision-maker's indifference level to violating constraints when compared to Marines waiting for training. For example, the author's penalty weight for $\overline{pRct}$ is 6.3. In isolation this penalty weight indicates that he would

prefer to have a Marine wait for training after MCT for any amount of time less than 6.3 weeks rather than recruit that Marine in a different trimester. In other words it is better to violate the maximum trimester recruiting limit by one if recruiting a Marine that trimester can reduce his wait time by more than 6.3 weeks.

2. Strictly Enforcing Constraints

Setting significance levels to 1.0 encourages strict enforcement of constraints. For example, with a significance level of 1.0 to pCGain, we expect (in the absence of other constraint violations) CGAIN to have value greater than zero only when it is necessary to provide a feasible solution.

3. Negating Constraints

The assignment of 0.0 for any significance level will allow the model to record violations of the associated elastic constraints but does not penalize for violations. Assignments of significance levels very near 0.0 has the practical effect of negating the associated constraint while guiding the model's choice among multiple optimal solutions.

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VI.   IMPLEMENTATION

A.   DATA

1.   Summary

LRAMS and STAR use data to describe the time link between a Marine's recruiting and MOS training, to penalize violations of constraints in the objective function, to bound variables, and to set initial conditions.

In LRAMs, there are three sets of data that describe personnel requirements, six sets for recruiting constraints, and seven sets for MOS training constraints. One set of data provides a time link between a recruitment date and a date to start MOS training. There are 11 sets of penalty weights, 13 sets of variable bounds, and seven sets of initial conditions.

In STAR, there are six sets of additional data that describe MOS training constraints due to class convening dates and class limits being published. There are three additional sets of penalty weights that apply to violations of the published class limits.

2.   Personnel Requirements

The Fiscal Year 2001 Classification Plan and the Accession Plan, produced by M&RA, form the basis for personnel requirements data. User input provides the allowed unpenalized deviation from the published Classification Plan before assessing a penalty. Table 2 provides a sample of these classification limits. The accession requirement is acesplan = 31,903.

$\underset{s}{g}$	$\underline{classify}_{gs}$		$\overline{classify}_{gs}$	
	female	male	female	male
0121	75	614	75	626
0151	98	602	98	614
0161	10	82	10	82
0231	14	140	14	142
0261	3	20	3	20

Table 2.   Sample of Annual Classification Limits By Gender and MOS (minimum and maximum number of Marines of gender g who train for each MOS s)

3. Recruiting

MCRC provides trimester recruiting limits (Table 3). M&RA provides monthly recruiting fractions based on historical results (Table 4 provides a sample). User inputs determine weekly recruiting fractions. This thesis uses $\underline{\text{rctfracm}}_w = 0.15 \, \forall w$ and $\overline{\text{rctfracm}}_w = 0.30 \, \forall w$.

t	1	2	3
$\underline{\text{rctt}}_t$	9,715	6,477	12,954
$\overline{\text{rctt}}_t$	11,263	7,743	17,599

Table 3.   Recruiting Limits By Trimester (minimum and maximum number of Marines who can be recruited during trimester t)

m	1	2	3	4	5	6	7	8	9
$\underline{\text{rctfract}}_m$	0.221	0.233	0.184	0.312	0.370	0.154	0.210	0.216	0.273
$\overline{\text{rctfract}}_m$	0.244	0.257	0.204	0.345	0.409	0.171	0.232	0.239	0.302

Table 4.   Sample of Trimester Recruiting Fraction Limits (minimum and maximum fraction of trimester's recruits who can be recruited during month m)

4. MOS Training Schools

M&RA provides minimum delays between the start of consecutive MOS school classes based on historical results. User input determines the maximum delay between consecutive MOS school classes and limits on the number of classes to start each year.

TECOM publishes class size limits for many training classes and training sequences for each MOS. Published class size limits, if they exist, form the basis for limits in the models. If class size limits are not published, the values are the total number of Marines to train divided by the historical number of classes scheduled. Table 5 provides a sample of MOS school data. Table 6 provides class size upper limits for a sample of common courses. Table 7 is a sample of convene$_{sw}$. Table 8 is a sample of gconvene$_{cw}$. Table 9 is a sample of $\overline{\text{gquota}}_{cw}$. Table 10 is a sample of $\overline{\text{quota}}_{sw}$. Table 11 is a sample of $\underline{\text{quota}}_{sw}$.

s	$\underline{crs}_{sw}\,\forall w$	$\overline{crs}_{sw}\forall w$	$\underline{delay}_s$	$\overline{delay}_s$	$\underline{numStrt}_s$	$\overline{numStrt}_s$
0121	**15**	**30**	**1**	**6**	**17**	**26**
0151	**15**	**30**	**1**	**6**	**17**	**26**
0161	**20**	**36**	**2**	**6**	**8**	**26**
0231	**20**	**30**	**4**	**12**	**4**	**13**
0261	**1**	**58**	**27**	**55**	**1**	**3**

Table 5.　　MOS School Data Sample (minimum and maximum number of Marines allowed in each course offering, minimum and maximum times between successive course offerings, and the minimum and maximum number of course offerings per year)

c	A1635X1	M092471	M0925U1	M092721	M09CGM1
$\overline{grp}_{cw}\forall w$	**50**	**45**	**50**	**30**	**30**

Table 6.　　Common Course Class Size Upper Limits Sample (maximum number of students in a course offering of common course c)

w $\quad$ s	1	2	3	4	5	6
0121	**1**	**0**	**1**	**0**	**0**	**1**
0151	**1**	**0**	**1**	**1**	**0**	**1**
0161	**1**	**0**	**1**	**0**	**1**	**0**
0231	**1**	**0**	**0**	**0**	**1**	**0**
0261	**0**	**0**	**0**	**1**	**0**	**0**

Table 7.　　Sample Data for convene$_{sw}$ (1 if Marines can begin training for MOS s in week w, 0 otherwise)

w $\quad$ c	1	2	3	4	5	6
A1635X1	**1**	**1**	**1**	**1**	**1**	**1**
M092471	**1**	**0**	**0**	**1**	**1**	**1**
M0925U1	**1**	**1**	**1**	**1**	**1**	**1**
M092721	**1**	**1**	**1**	**0**	**1**	**1**
M09CGM1	**0**	**0**	**1**	**0**	**0**	**0**

Table 8.　　Sample Data for gconvene$_{cw}$ (1 if Common Course c is Offered in Week w, 0 otherwise)

w c	1	2	3	4	5	6
A1635X1	50	50	50	50	50	50
M092471	25	0	0	26	1	26
M0925U1	37	38	38	38	38	38
M092721	25	25	55	0	25	26
M09CGM1	0	0	23	0	0	0

Table 9.   Sample Data for $\overline{gquota}_{cw}$ (the maximum number of Marines authorized to start common course c in week w)

w s	1	2	3	4	5	6
0121	15	0	15	0	0	15
0151	15	0	15	15	0	15
0161	4	0	5	0	4	0
0231	19	0	0	0	19	0
0261	0	0	0	1	0	0

Table 10.   Sample Data for $\underline{quota}_{sw}$ (the minimum number of Marines authorized to start training for MOS s in week w)

w s	1	2	3	4	5	6
0121	27	0	27	0	0	46
0151	28	0	28	28	0	28
0161	4	0	5	0	4	0
0231	38	0	0	0	38	0
0261	0	0	0	24	0	0

Table 11.   Sample Data for $\overline{quota}_{sw}$ (Maximum Number of Marines Authorized to Start Training for MOS s in Week w)

5.   Initial Training

M&RA provides historical time links between Marines' recruitment and MCT graduation. Table 12 provides a sample of the historical proportions of Marines recruited in week w who graduate from MCT w' weeks later.

w w'	1	2	3	4	5	6	7	8
17	0.13	0.17	0.20	0.28	0.33	0.38	0.35	0.38
18	0.38	0.31	0.30	0.27	0.23	0.23	0.25	0.21
19	0.23	0.23	0.20	0.16	0.13	0.10	0.10	0.10
20	0.12	0.12	0.13	0.10	0.12	0.09	0.11	0.07
21	0.02	0.02	0.01	0.02	0.02	0.03	0.02	0.03
22	0.01	0.02	0.02	0.01	0.02	0.01	0.03	0.04
23	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
25	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.01
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	0.02	0.03	0.04	0.03	0.02	0.03	0.02	0.02

Table 12.   Distribution of Times to MCT Graduation (historical proportions of Marines recruited in week w who graduate from MCT w' weeks later: this applies to Marines of both genders)

6.   Penalty

The penalty values are the product of a penalty weight (Table 1 in Chapter V), a discount factor (Table 13 and Table 14), and a nonlinear factor, NLF_r (Table 15), used to approximate a nonlinear penalty function.

t	1	2	3	4	5	6
Discount factor	1	0.984	0.968	0.4	0.38	0.36

Table 13.   Penalty Discount Factors by Trimester (used to give greater penalties for violations occurring earlier in the models)

m	1	2	3	4	5	6
Discount factor	1	0.996	0.992	0.988	0.984	0.98

m	7	8	9	10	11	12
Discount factor	0.976	0.972	0.968	0.964	0.96	0.956

m	13	14	15	16	17	18
Discount factor	0.4	0.396	0.392	0.388	0.384	0.38

m	19	20	21	22	23	24
Discount factor	0.376	0.372	0.368	0.364	0.36	0.356

Table 14.   Penalty Discount Factors by Month (used to give greater penalties for violations occurring earlier in the models)

r		1	2	3	4	5	6
NLF_r		**1**	**3**	**8.833**	**15.25**	**24.7**	**35.33**
r		7	8	9	10	11	12
NLF_r	**48.643**	**63.375**	**80.611**	**99.400**	**120.591**	**143.417**	

Table 15.   Sample of Nonlinear Factors, NLF_r (used to approximate nonlinear penalty functions)

7.   Variable Bounds

For all variables subscripted by r, the upper bound is set to r until the sum over r of the bounds reaches the upper limit described by the product of relevant data and a user-defined bounding factor. Table 16 lists relevant data and bounding factors. Table 17 provides a sample of $\underline{rctw}_{gp}$ and $\overline{rctw}_{gp}$.

Summed Upper Bound	Relevant Data	STAR Bounding Factor	LRAMS Bounding Factor
$\sum_r \mathrm{mCGain}_{pr} \forall p$	$\sum_{g,s\in\mathrm{MOSgrp}_p} \underline{\mathrm{classify}}_{gs}$	0.1	0.1
$\sum_r \overline{\mathrm{mClass}}_{grs} \forall gs$	$\overline{\mathrm{classify}}_{gs}$	0.3	0.3
$\sum_r \underline{\mathrm{mClass}}_{grs} \forall gs$	$\underline{\mathrm{classify}}_{gs}$	0.1	0.1
$\sum_r \overline{\mathrm{mClassp}}_{gpr} \forall gp$	$\sum_{s\in\mathrm{MOSgrp}_p} \overline{\mathrm{classify}}_{gs}$	0.3	0.3
$\sum_r \underline{\mathrm{mClassp}}_{gpr} \forall gp$	$\sum_{s\in\mathrm{MOSgrp}_p} \underline{\mathrm{classify}}_{gs}$	0.1	0.1
$\sum_r \overline{\mathrm{mCourse}}_{cmr} \forall cm$	$\max\{\overline{\mathrm{grp}}_{cw} \forall w \in \mathrm{week}_m\}$	0.3	0.7
$\sum_r \overline{\mathrm{mProp}}_{mr}$ $\forall t, m \in \mathrm{month}_t$	$\overline{\mathrm{rctt}}_t \overline{\mathrm{rctfract}}_m$	0.2	0.3
$\sum_r \underline{\mathrm{mProp}}_{mr}$ $\forall t, m \in \mathrm{month}_t$	$\underline{\mathrm{rctt}}_t \underline{\mathrm{rctfract}}_m$	0.2	0.3
$\sum_r \overline{\mathrm{mRct}}_{rt} \forall t$	$\overline{\mathrm{rctt}}_t$	0.1	0.2
$\sum_r \underline{\mathrm{mRct}}_{rt} \forall t$	$\underline{\mathrm{rctt}}_t$	0.1	0.2
$\sum_r \overline{\mathrm{mSeat}}_{mrs} \forall ms$	$\max\{\overline{\mathrm{crs}}_{rsw} \forall w \in \mathrm{week}_m\}$	0.3	0.7
$\sum_r \underline{\mathrm{mSeat}}_{mrs} \forall ms$	$\max\{\underline{\mathrm{crs}}_{rsw} \forall w \in \mathrm{week}_m\}$	1.0	0.75
$\sum_r \mathrm{mWait}_{gmpr} \forall gmp$	$\sum_{s\in\mathrm{MOSgrp}_p} \underline{\mathrm{classify}}_{gs}$	0.5	0.75

Table 16.   Summed Upper Bounds for All *r* Subscripted Variables. Upper bounds are the product of relevant upper bounds and bounding factors.

		$\underline{rctw}_{gp}$		$\overline{rctw}_{gp}$	
g		female	male	female	male
p					
AE		0	5	6	48
AF		0	10	7	98
AG		0	2	1	22
AJ		0	2	1	24
BA		1	9	10	82

Table 17.　Sample Data for $\underline{rctw}_{gp}$ and $\overline{rctw}_{gp}$ (weekly recruiting limits for gender g and enlistment program p)

8.　Initial Conditions

$\overline{cCourse}_{cw} = 0 \ \forall cw$. Table 18 provides a sample of cMCTgrad$_{gpw}$. Table 19 provides all nonzero values of $\underline{cSeat}_{sw}$ and $\overline{cSeat}_{sw}$. Table 20 provides a sample of cTrain$_{gsw}$. Table 21 provides a sample of cWait$_{gpw}$. Table 22 provides a sample of eStart$_s$.

g	p \ w	1	2	3	4	5	6
male	AE	27	35	37	30	16	9
	AF	39	55	61	48	28	19
	AG	12	16	17	14	13	14
	AJ	13	17	19	15	9	8
	BA	36	45	44	35	23	14
	BX	15	13	11	9	6	4
female	AE	0	0	0	0	0	0
	AF	0	0	0	0	0	0
	AG	0	0	0	0	0	0
	AJ	0	0	0	0	0	0
	BA	2	2	2	1	1	1
	BX	3	3	3	3	1	0

Table 18.　Sample Data for cMCTgrad$_{gpw}$ (number of Marines from the previous year's recruiting class of gender g recruited under enlistment program p who are expected to graduate from MCT in week w)

	$\underline{cSeat}_{sw}$		$\overline{cSeat}_{sw}$	
w	1	2	1	2
s				
0613	**0**	**10**	**0**	**0**
2831	**0**	**1**	**0**	**0**
3521	**3**	**0**	**0**	**0**
4066	**0**	**1**	**0**	**0**
1341	**0**	**0**	**0**	**1**

Table 19.   Nonzero Data For $\underline{cSeat}_{sw}$ and $\overline{cSeat}_{sw}$ (number of Marines from the previous year's recruiting class who are scheduled to begin training for MOS s in week w who are beyond the class size limit for the first MOS-unique course in their training sequence). all other MOSs s and weeks w are 0.

	g	male		female	
	w	1	2	1	2
s					
0121		**0**	**0**	**0**	**0**
0151		**0**	**0**	**0**	**0**
0161		**0**	**25**	**0**	**2**
0231		**0**	**0**	**0**	**0**
0261		**0**	**0**	**0**	**0**

Table 20.   Sample Data For $cTrain_{gsw}$ (number of Marines of gender g from the previous year's recruiting class who are scheduled to begin training for MOS s in week w)

	g	male		female	
	w	1	2	1	2
p					
AE		**0**	**0**	**0**	**0**
AF		**9**	**0**	**0**	**0**
AG		**0**	**0**	**0**	**0**
AJ		**0**	**0**	**0**	**0**
BA		**0**	**10**	**0**	**1**
BX		**1**	**2**	**0**	**2**

Table 21.   Sample Data For $cWait_{gpw}$ (number of Marines of gender g and enlistment program p from the previous year's recruiting class who are scheduled to wait for 1 week in week w before starting their MOS school training)

s	0121	0151	0161	0231	0261
eStart$_s$ in LRAMS	1	1	4	1	6
eStart$_s$ in STAR	53	53	53	55	58

Table 22.   Sample Data For eStart$_s$ (earliest allowable start date for Marines to begin training for MOS s)

B.   COMPUTING TOOLS

LRAMS and STAR are implemented using the General Algebraic Modeling System (GAMS) [Brooke, Kendrick, Meeraus, and Ramam 1998] on a Pentium III/ 700 megahertz desktop computer with Windows NT operating system and 1 gigabyte of Random Access Memory (RAM).

C.   COMPUTATIONAL ISSUES

1.   Scale

LRAMS and STAR are both too large to easily solve on personal computers with up to 1 gigabyte of RAM. LRAMS contains 1.6 million variables (20,400 binary) and 113 thousand constraints. STAR contains 1.6 million variables (10,200 binary) and 94 thousand constraints. Table 23 lists the dimensions associated with the indices used in the model.

Index	Size
Common course c	41
Gender g	2
Month m	24
Enlistment program p	15
Range r	30
MOS s	196
Trimester t	6
Week w	104

Table 23.   Index Dimensions (dimensions of the indices used in the models)

There are two natural methods (by MOS and time) to decompose both LRAMS and STAR and solve the resulting decomposed pieces sequentially. For example, if there are 200 MOSs, the model may solve the first 70 MOSs, then the next 70, and finally the last 60. The binary variable START$_{sw}$ is also split into (START$_{sw}$ + STARTC$_{sw}$). The variable STARTC$_{sw}$ is defined the same as the variable START$_{sw}$ except that it is

continuous from 0 to 1. For all MOSs s and weeks w, either $START_{sw}$ or $STARTC_{sw}$ is set to 0 while the model determines the value of the other variable. For example, $START_{sw} = 0$ for all weeks $w > 75$ and for all MOSs s after the 50th MOS. $STARTC_{sw} = 0$ if week $w < 76$ and MOS s is one of the first 50. After solving this instance, the modeler can fix these START variable values to those obtained and a new problem can be solved for an additional 50 MOSs for each of the first 75 weeks. New modeling parameters that support this solution method are defined below.

Indices

i iteration

Data

$\underline{bMos}_i, \overline{bMos}_i$ the first and last MOS s to use the binary variable $START_{sw}$ in iteration i

$\underline{bWeek}_i$ the first week w to use the continuous $[0,1]$ variable $STARTC_{sw}$ for all MOSs s in iteration i

$fStarts_i, \overline{fStarts}_i$ in iteration i, the first and last MOS s for which the binary variable $START_{sw}$ is fixed to the value obtained in the solution of iteration i -1

$\overline{fStartsw}_i$ in iteration i, the last week w for which the binary variable $START_{sw}$ is fixed to the value obtained in the solution of iteration i -1

$\underline{Mos}_i, \overline{Mos}_i$ the first and last MOS s to be considered in the solution of the model in iteration i

We define a new name Heuristic LRAMS (HLRAMS) to refer to LRAMS when it is solved in this iterative manner. The similar term Heuristic STAR (HSTAR) refers to STAR when it is solved in this manner. We use the terms Reduced LRAMS$_i$ (RLRAMS$_i$) and Reduced STAR$_i$ (RSTAR$_i$)to refer to the submodels of LRAMS and STAR solved in iteration i. An example of RLRAMS$_i$ is shown graphically in Figure 8.
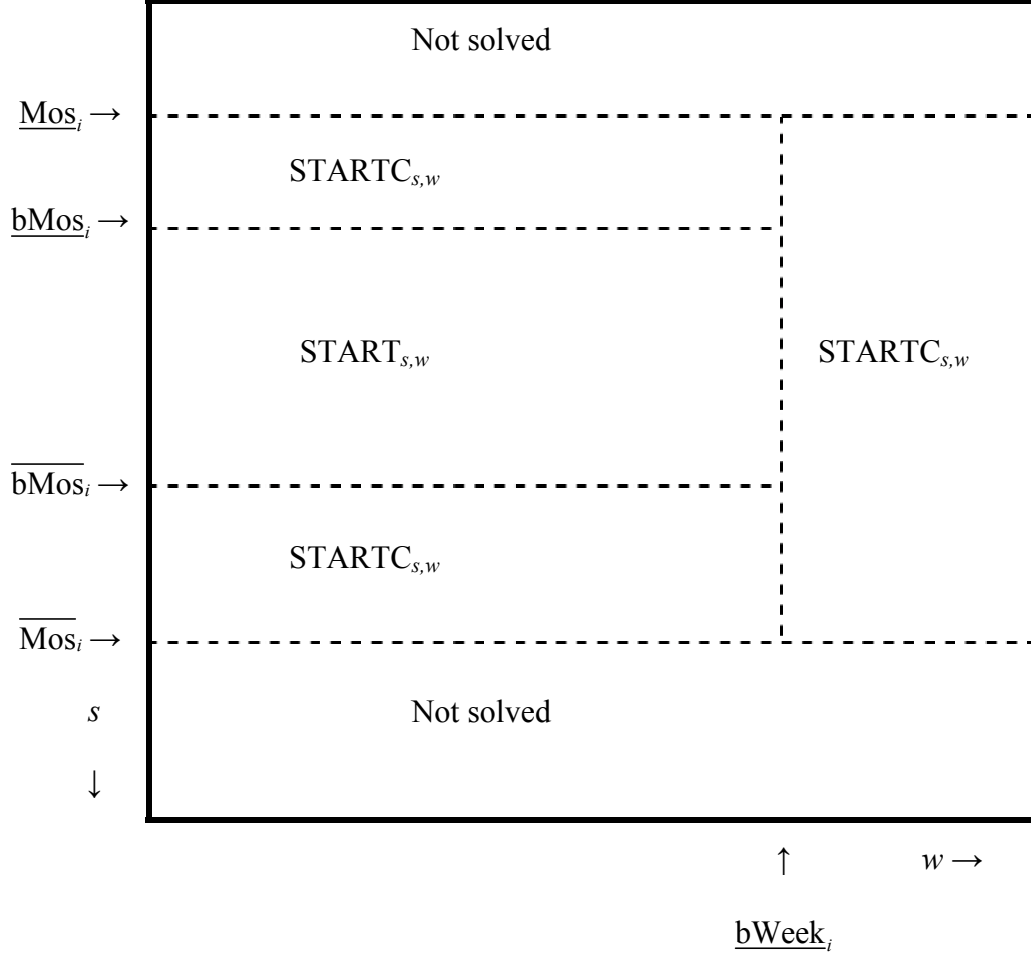
Figure 8. Reduced LRAMS$_i$ (RLRAMS$_i$). The models are setup to solve iteratively. The term RLRAMS$_i$ refers to the submodel of LRAMS solved in iteration i. The first $\underline{Mos_i}$ - 1 MOSs and the MOSs after the first $\overline{Mos_i}$ are not solved in iteration i. The binary variable START$_{sw}$ is used in the solution for MOSs between the first $\underline{bMos_i}$ and the first $\overline{bMos_i}$ for weeks $\leq$ $\underline{bWeek_i}$. For other combinations of MOS s and week w in the solution set, the continuous variable STARTC$_{sw}$ is used.

We solve HLRAMS in seven iterations using the binary START variable for the first 75 weeks and the continuous STARTC variable thereafter. In each of the first six iterations, RLRAMS$_i$ solves for the START variable over a new range of MOSs and retains the values from previous solutions. In iteration seven, RLRAMS$_i$ solves all MOSs simultaneously as a linear program with all START values fixed to solutions obtained in iterations one to six. The specific data are shown in Table 24. HLRAMS solves in three

hours 24 minutes when solving each iteration with a solution guaranteed to be within 10 percent (five hours 59 minutes to within five percent) of the optimal solution.

Because solving each iteration separately to within 10 percent of optimal does not guarantee a final solution within 10 percent of optimal, the linear program relaxation of LRAMS is solved and indicates the solution produced using this cascading approach is within 9.8 percent of optimality.

HSTAR solves in a single iteration using the binary START variable for the first 75 weeks and the continuous STARTC variable thereafter. STAR solves in 39 minutes to within one percent of the optimal solution.

model	RLRAMS$_i$						
i	1	2	3	4	5	6	7
$\underline{\underline{bMos}}_i$	1	1	1	1	1	1	1
$\overline{\overline{bMos}}_i$	33	65	98	130	163	196	196
$\overline{bWeek}_i$	75	75	75	75	75	75	75
$\underline{fStarts}_i$	0	1	1	1	1	1	1
$\overline{\overline{fStarts}}_i$	0	33	65	98	130	163	196
$\overline{\overline{fStartw}}_i$	0	75	75	75	75	75	75
$\underline{Mos}_i$	1	34	66	99	131	164	1
$\overline{\overline{Mos}}_i$	33	65	98	130	163	196	196

Table 24.   Iterative Solution Settings. HLRAMS solves in seven iterations using the binary START variable for the first 75 weeks and the continuous STARTC variable thereafter. In each of the first six iterations, LRAMS solves for the START variable over a new range of MOSs and retains the values from previous solutions. In iteration seven, all START values are fixed to previous solutions and all MOSs are solved simultaneously as a linear program.

2.   Initial Conditions

Each time STAR is run for a given fiscal year, it saves a snapshot of MCT graduations throughout the second year and training and waiting information from weeks 53 and 54. LRAMS and STAR use this information as initial conditions for the following fiscal year's run. Because no previous information of this type exists, and assuming that steady-state conditions exist from one year to the next, we develop initial conditions by running STAR several times for fiscal year 2001. After each run, the initial conditions

data are saved for use in the next fiscal year 2001 run. After several runs, the initial conditions are relatively unchanging.

The transfer of information from year to year causes problems in certain MOS and gender combinations with small nonzero requirements in the Classification Plan. In some of these cases, large buildups begin to accumulate in the initial conditions data passed from one STAR run to the next. As an example, the Classification Plan requires that two males train for MOS 5526 (Oboe Player). After several runs of the model, the initial conditions data contain more than 20 males training for 5526. To resolve this problem, we add to STAR the ability to reduce the number of Marines carried over to a user-defined fraction (set to 0.75) of the Classification Plan for each gender and MOS combination.

3. MOS School Data

a. *Multiple Training Tracks*

49 of the MOSs have multiple training sequences available. For modeling simplicity, the author assumes that all tracks for a given MOS have equal capacity and scheduling limitations. Maximum class sizes and quotas for the first training sequence are multiplied by the number of sequences available to produce maximum class sizes and quotas.

b. *Early Course Offerings*

In the case of some MOSs, the only course offerings occur so early in the fiscal year that classification limits can not be satisfied unless there are enough Marines early enough in the initial conditions data to meet the requirement. As an example, the Classification Plan requires that three males and zero females be trained for MOS 5528 (Bassoon Player) during the fiscal year. The training course for this MOS is only offered in weeks two and six. Any upper bound on the variable for classifying too few Marines that is less than three for male 5528s causes the model to be infeasible unless some Marines are carried over from the previous year prior to week four. In order to ensure feasibility, the data $convene_{sw}$ and $gconvene_{cw}$ are set to one for all MOSs and common courses in week 52. No upper bounds are set for violating maximum class size limits constraints in week 52 but the penalty is 100 times larger than that for violating maximum class size limits in other weeks of month 12.

c.   Limited Training Seats

For 65 of 196 MOSs, there are not enough MOS training school seats during fiscal year 2001 to satisfy the Classification Plan. For 28 of 196 MOSs, the shortage of seats is more than 20 percent of the Classification Plan. This causes infeasibility in STAR when the upper bound for violating maximum class sizes is set to "reasonable" limits. For example, the Classification Plan requires that 56 Marines train for MOS 2131 (Towed Artillery Systems Technician). TECOM provides 42 seats during the fiscal year in eight course offerings. The maximum class size limit is six Marines. If the maximum allowable violation of maximum class size limits is set to 15% of that limit, then the largest allowable constraint violation is one Marine per course offering or eight Marines during the fiscal year. Under these circumstances, even with ideal course timing, only 50 Marines can be trained. This is more than 10 percent below the Classification Plan requirement and results in an infeasible model. In order to correct this issue, the author adds enough seats in week 52 to exactly make up any deficit in the annual allotment when compared to the Classification Plan. The common courses are similarly adjusted.

d.   Implied Training Bounds

For each MOS, the maximum number of course offerings, the maximum class size and maximum allowable number to seat beyond the maximum class size work together to produce an implied upper bound on the number of Marines that train for a given MOS in the first year. The minimum number of Marines to classify into the MOS and its maximum allowable violation work together to produce an implied lower bound the number of Marines that train for a given MOS in the first year. For one MOS, 6173 (CH-53 Helicopter Crew Chief), the implied training boundaries cause infeasibilities in LRAMS. For MOS 6173, the upper bound for the OVERSEAT variable is removed to allow the model to provide useful results. The data in Table 25 illustrate this issue.

Similarly, implied lower bounds result from the minimum number of class starts, minimum class size and maximum violation of the minimum class size. For each MOS, an implied upper bound results from the maximum number of Marines to classify into the MOS and the maximum allowable violation of this limit. For two MOSs, 0613 (Construction Wireman) and 0624 (High Frequency Communication Central Operator),

the implied training boundaries cause infeasibilities in LRAMS. For these MOSs, the upper bound for the UNDERSEAT variable is removed to allow the model to provide useful results.

Bound Types	Values for MOS 6173
$\overline{\overline{numStrt}}_s$	**31**
$\overline{\overline{crs}}_{sw} \forall w$	**1**
Upper bound for $\sum_r \overline{mSeat}_{mrs} \forall m$	**1**
Implied upper bound for $\sum_{g, w \leq 52} TRAIN_{gsw}$	**62**
$\sum_g \underline{classify}_{gs}$	**73**
Upper bound for $\sum_{gr} \underline{mClass}_{grs}$	**8**
Implied lower bound for $\sum_{g, w \leq 52} TRAIN_{gsw}$	**65**

Table 25.   Conflict in Implied Training Bounds for MOS 6173 (CH-53 Helicopter Crew Chief). For this MOS, the maximum number of Marines that can train in each convening class is two (the sum of the maximum class size and the maximum class size violation limit). The maximum number of convening classes per fiscal year is 31 so the implied maximum number of Marines who can train each fiscal year is 62 (the product of two and 31). With the minimum number to train set at 73 Marines and the maximum violation set at eight Marines, the implied lower training bound is 65 Marines (the difference between 73 and eight). The model cannot satisfy both the requirement to train at least 65 Marines and the requirement to satisfy no more than 62 Marines: an infeasibility results.

D.   RESULTS

1.   LRAMS

LRAMS' primary result is a training request detailing when Marines should begin training at the first course in their MOS school training sequence. The training request is broken down by course convening week, gender, and MOS. LRAMS' secondary result is a Program Plan outlining when recruiters should ship recruits to Recruit Training. The Program Plan is broken down by week, gender, and enlistment program. Table 26 is a partial summary of LRAMS' training request by MOS and month. Using MOS 0121 as an example, 44 Marines start the first MOS training school in their MOS training sequence during the first month (October) of fiscal year 2001; 14 of these Marines start training in week three and 30 in week four.

Table 27 is a partial summary of LRAMS' draft Program Plan by enlistment program and month. For example, MCRC should ship 180 new Marines of enlistment program AE to Recruit Training in month one. This figure consists of 24 males and three females in week one, 48 males and six females in week two, 40 males and 5 females in week three, and 48 males and six females in week four. Figure 9 shows the values of key variables impacted by the recruiting market summed over each calendar month. Surges in recruiting result in dampened surges in training and numbers of Marines waiting for training approximately four months later. Figure 10 shows that the amount of time Marines wait for their first MOS training school to convene dominates elastic constraint violations.

s \ m	1	2	3	4	5	6	7	8	9	10	11	12
0121	44	89	29	80	29	46	45	30	61	103	61	91
0151	29	30	29	75	121	58	86	122	61	0	91	15
0161	27	10	8	10	0	10	5	10	0	8	10	0
0231	20	31	31	20	0	0	20	0	0	36	0	0
0261	0	0	0	27	0	0	0	0	0	0	0	0

Table 26.   LRAMS' Training Request (partial summary of the number of Marines planned to begin the first course in their MOS school sequence during each month). For example, 44 Marines begin training for the 0121 MOS during the first month: of these, zero begin in weeks one and two, 14 in week three and 30 in week four.

p \ m	1	2	3	4	5	6	7	8	9	10	11	12
AE	180	131	104	46	33	21	25	33	181	96	33	33
AF	165	172	139	68	177	43	81	198	333	43	263	118
AG	15	34	17	17	22	9	13	48	78	35	56	52
AJ	17	18	52	17	17	9	13	29	85	66	63	44
BA	67	71	81	232	81	51	113	67	279	75	280	173

Table 27.   LRAMS' Draft Program Plan (partial summary of the number of new Marines shipping to Recruit Training each month). Using enlistment program AE as an example, 180 new Marines ship to Recruit Training during the first month of the fiscal year: 24 males and three females in week one, 48 males and six females in week two, 40 males and five females in week three, and 48 males and six females in week four.
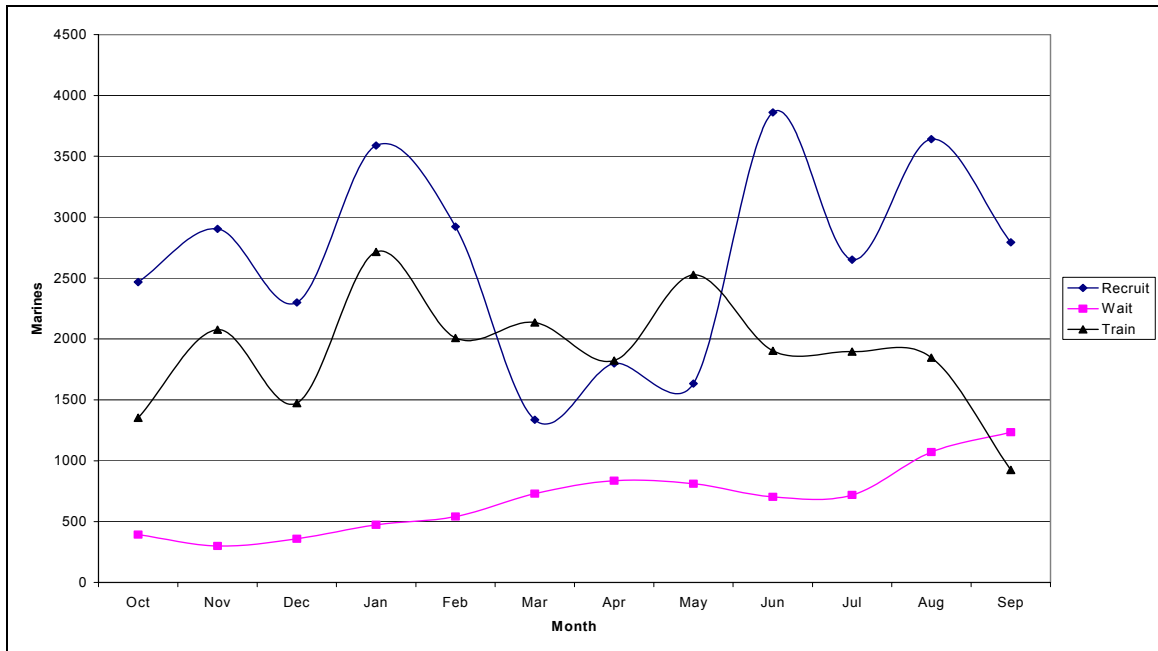
Figure 9.   LRAMS Flow Relations. The number of Marines recruited effects the numbers training and waiting after dampening and time delay. For example, the January recruiting surge causes a less dramatic training surge in May. Recruiting surges are greatly dampened in training response and numbers waiting for training four months later. The plotted values are summations of the variables by month for fiscal year 2001.
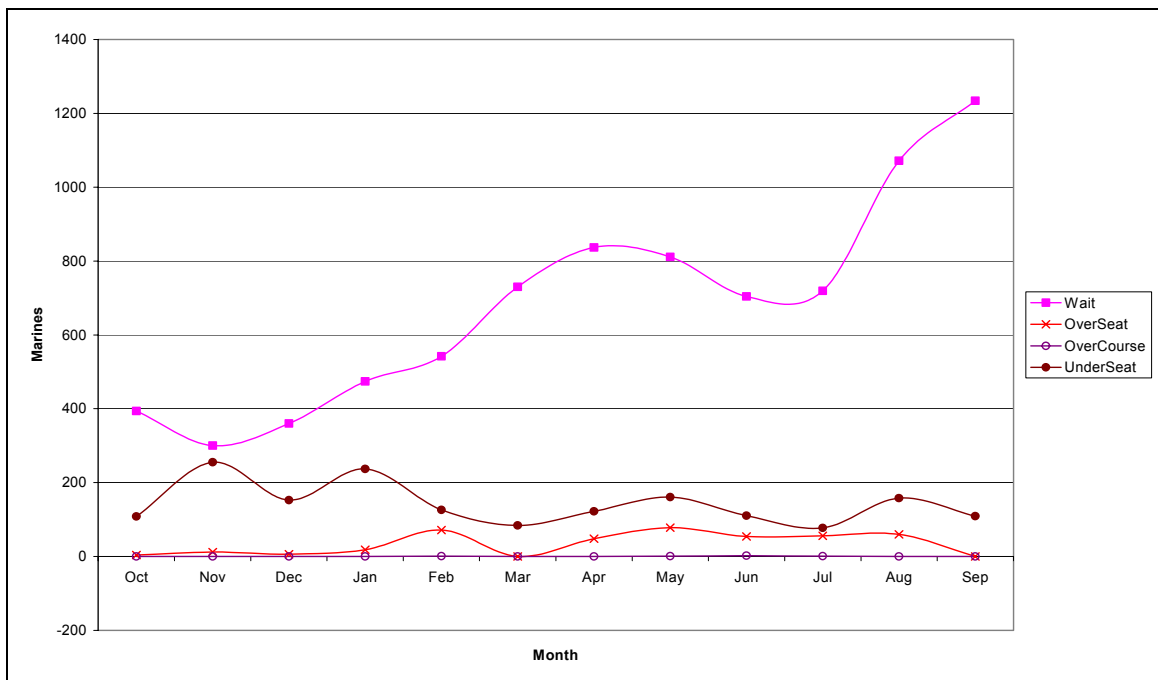

Figure 10.   LRAMS Training-related Objective Function Variable Values. Breaking LRAMS' objective function into pieces by month of fiscal year 2001 illustrates that the number of Marines waiting for training dominates elastic constraint violations.

2. STAR

STAR's primary result is a Program Plan outlining when recruiters should ship recruits to Recruit Training. The Program Plan is broken down by week, gender, and enlistment program. Table 28 is a partial summary of STAR's Program Plan by enlistment program and month. STAR's secondary result is a MOS training school seat fill plan detailing how many Marines begin training at the first course in their MOS school training sequence at each course offering. The training request is broken down by course convening week, gender, and MOS. Table 29 is a partial summary of STAR's MOS training school seat fill plan by MOS and month. Figure 11 shows the values of key variable related to the recruiting market summed over each calendar month. When comparing this figure to its counterpart (Figure 9) from LRAMS, one notices that the recruiting and training curves are similar, but the waiting plot is very different. LRAMS' ability to consider the schedules of multiple MOSs concurrently explains this. In the current planning system (that produced schedules used in STAR) each MOS school develops its schedule in isolation. Figure 12 shows training-related elastic variables and the WAIT variable to illustrate that Marines waiting for training dominate constraint violations.

m p	1	2	3	4	5	6	7	8	9	10	11	12
AE	33	35	108	115	98	87	33	33	33	25	160	158
AF	67	253	90	162	235	43	67	67	344	150	176	147
AG	13	18	30	26	31	11	13	13	18	73	73	73
AJ	10	17	17	33	29	11	16	13	80	42	80	80
BA	44	67	92	154	171	66	67	67	280	240	67	252

Table 28. STAR's Program Plan (partial summary of the number of new Marines to ship to Recruit Training each month)

m s	1	2	3	4	5	6	7	8	9	10	11	12
0121	15	102	16	115	91	31	59	96	63	40	39	39
0151	56	86	15	85	85	53	53	116	48	47	53	21
0161	4	9	0	7	8	12	7	15	12	12	8	4
0231	0	36	0	40	0	30	13	8	12	13	0	10
0261	11	0	0	0	0	0	0	17	0	0	0	0

Table 29. STAR's MOS Training School Seat Fill Plan (partial summary of the number of Marines to begin the first course in their MOS school training sequence each month)
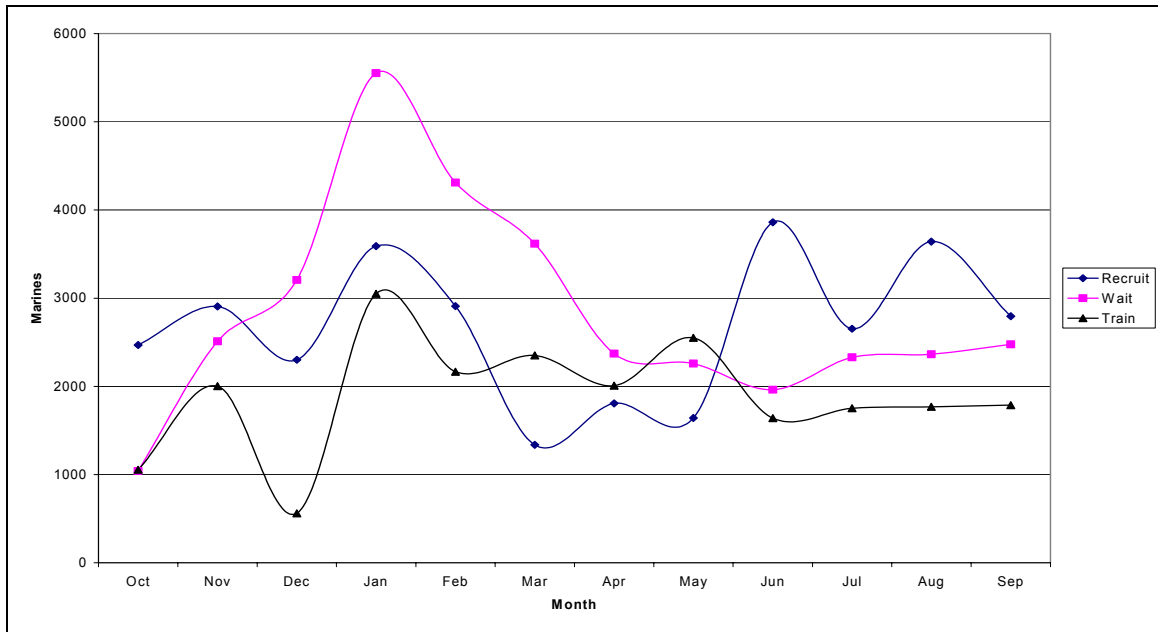
Figure 11.   STAR Flow Relations. Low response to training needs in early months result in large numbers of Marines waiting for training. The plotted values are summations of the variables by month for fiscal year 2001. Note that when comparing STAR results to LRAMS results (see Figure 9), recruiting and training numbers are similar, but waiting is much different. This can be explained by LRAMS' ability to choose schedules that are coordinated across MOSs. The current planning cycle (used to produce schedules used by STAR), allows MOS schools to prepare schedules in isolation.
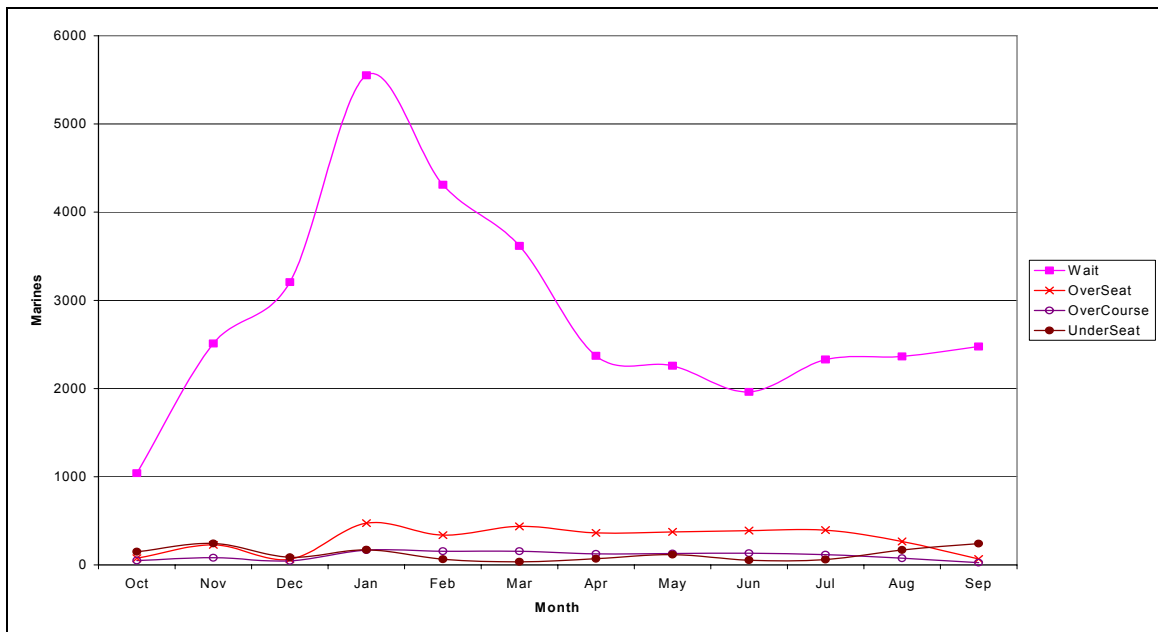

Figure 12.   STAR Training-related Objective Function Variable Values. The number of Marines waiting for training dominates elastic constraint violations.

3. Results Summary

Summed model results for the fiscal year for LRAMS and STAR are listed in Table 30. Noteworthy differences in model results are in MOS school training violations, waiting, and the objective function. These differences all relate to the relative scheduling flexibility allowed in the models.

Result	LRAMS	STAR
Objective Function Value (Marine-weeks)	**470,301**	**514,601**
WAIT (Marine-weeks)	**8,177**	**33,987**
CGAIN (Marines)	**109**	**113**
$\overline{\text{CLASS}}$ (Marines)	**481**	**479**
$\overline{\text{CLASSP}}$ (Marines)	**605**	**606**
$\underline{\text{CLASS}}$ (Marines)	**0**	**2**
$\underline{\text{CLASSP}}$ (Marines)	**0**	**0**
$\underline{\text{RCT}}$ (Marines)	**0**	**0**
$\overline{\text{RCT}}$ (Marines)	**6**	**6**
$\overline{\text{PROP}}$ (Marines)	**52**	**58**
$\underline{\text{PROP}}$ (Marines)	**80**	**73**
$\overline{\text{COURSE}}$ (Marines)	**5**	**1,259**
$\overline{\text{SEAT}}$ (Marines)	**492**	**3,466**
$\underline{\text{SEAT}}$ (Marines)	**2,235**	**1,463**
RECRUIT (Marines)	**31,903**	**31,903**
Number of this year's recruits expected to graduate from MCT (Marines)	**29,133**	**29,133**
TRAIN (non-infantry Marines)	**22,689**	**22,682**

Table 30.   Results Summary For LRAMS and STAR For Fiscal Year 2001

E.   USING LRAMS TO EVALUATE POLICY DECISIONS

Policy decisions in MCRC, TECOM, and M&RA are often easy to quantify in terms of cost, but it is much more difficult for decision-makers to predict the magnitude of the associated benefits. Though the primary purpose of LRAMS is to recommend coordinated schedules for the recruiting and MOS training of new Marines, it can also forecast the impact of certain policy decisions on manning levels in the Marine Corps. This forecasting ability is not currently available to Marine Corps planners. The following paragraphs describe how adjustments to the LRAMS base case data for fiscal year 2001 show the influence of some potential policy decisions on manning levels

(results listed below apply to HLRAMS when each iteration is solved to within 10 percent of the optimal solution).

1. MOS School Adjustments

The author considers slightly increasing the maximum class size in the 10 schools most "overbooked" in the base case. For each of these MOSs, the maximum classroom size is increased by 10% over current limits. This represents the amount of increase that might be possible with relatively small adjustments in the schools such as the addition of an instructor or the purchase of additional training equipment. With this adjustment, LRAMS predicts a reduction in the amount of time Marines wait for training from 8,177 to 7,960 Marine-weeks, a 2.7% improvement.

The author considers halving the minimum delay between consecutive class offerings (or if minimum delay is 1 week in the base case, doubling the maximum class size) and doubling the maximum number of course offerings in the year in the 10 schools most "overbooked" in the base case. This represents the amount of increase that might be possible with significant adjustments such as the addition of an alternate training track or the building of a new classroom. With this adjustment, LRAMS predicts a reduction in the amount of time Marines wait for training from 8,177 to 8,058 Marine-weeks, a 1.5% improvement.

The author considers ignoring the minimum class size in all schools. This represents the potential of a significant philosophy shift in TECOM. With this adjustment, LRAMS predicts a reduction in the amount of time Marines wait for training from 8,177 to 5,543 Marine-weeks, a 32.2% improvement.

2. Recruiting Adjustments

The author considers slightly increasing the maximum recruiting limit in the most difficult recruiting trimester. For the trimester made up of February, March, April, and May, the maximum recruiting limit is increased by 5% over current limits. This represents the amount of increase that might be possible with the addition of more full-time or part-time recruiters or perhaps a new advertising campaign. With this adjustment, LRAMS predicts an increase in the amount of time Marines wait for training from 8,177 to 8,475 Marine-weeks. This increase comes with a large decrease in the total quantity of class size violations.

The author considers slightly decreasing the minimum recruiting limit in the least difficult recruiting trimester. For the trimester made up of June, July, August, and September, the minimum recruiting limit is decreased by 5% over current limits. This represents the potential of a significant philosophy shift in MCRC. With this adjustment, LRAMS predicts an increase in the amount of time Marines wait for training from 8,177 to 9,138 Marine-weeks. This increase comes with a large decrease in the total quantity of minimum class size violations.

3.   Manpower Planning Adjustments

The author considers allowing up to 5% deviations from the Classification Plan. Unpenalized deviation limits from the published Classification Plan are increased from the 1% used in the base case to 5%. This represents the potential of a philosophy shift in M&RA. With this adjustment, LRAMS predicts a reduction in the amount of time Marines wait for training from 8,177 to 6,710 Marine-weeks, a 17.9% improvement.

The author considers the impact of reducing the Accession Plan by 5%. This represents the potential impact of a leadership campaign aimed at reducing attrition at Recruit Training and in operational units. With this adjustment, LRAMS predicts a reduction in the amount of time Marines wait for training from 8,177 to 7,833 Marine-weeks, a 4.2% improvement.

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VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

In fiscal year 1998, new Marines spent over 2,700 Marine-years wait time in an unproductive status while waiting on their next training schools to convene [Goodrum 2001]. Assuming that the majority of this wasted time was new MCT graduates waiting for their first MOS school to convene, LRAMS and STAR focus on reducing this portion of the total waiting time. Model results using fiscal year 2001 accessions data indicate that wait time between MCT and the first MOS training schools can potentially be reduced to 160 Marine-years.

Though LRAMS' primary purpose is to assist planners to develop coordinated Program Plans and MOS Training requests, it can also forecast the impact of policy decisions of MCRC, TECOM, and M&RA on manning levels in the Marine Corps. Currently, no other Marine Corps planning tool provides this information to decision-makers.

B. RECOMMENDATIONS

We recommend that M&RA adopt LRAMS and STAR. M&RA planners can make significant improvements over current methods for scheduling the recruiting and training of new Marines through the use of LRAMS and STAR. We recommend M&RA use LRAMS to make MOS school training requests to better shape training schedules. We recommend M&RA use STAR to develop Program Plans, adjusted to published MOS school training schedules.

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